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PREFACE

This volume contains all of the papers presented at the New York meeting in February, 1918, excepting those on Iron and Steel and Metallography of Steel, which were included in Vol. LVIII, and supersedes all Bulletins up to and including No. 134, February, 1918.

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PROCEEDINGS OF THE ONE HUNDRED SIXTEENTH MEETING OF THE INSTITUTE, NEW YORK

Feb. 18 to 21, 1918

Committee on Arrangements

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F. T. RUBIDGE
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Luncheon Committee

E. MALTBY SHIPP, *Chairman*

ALBERT D. BEERS
CHARLES A. BOHN
P. A. MOSMAN

Committee on Visit to Subway

ROBERT M. RAYMOND

As was to be expected, the double pressure under which many members of the Institute are now laboring in the service of the Government, made the attendance of the one hundred and sixteenth meeting somewhat smaller than usual. On the other hand, the opportunity for each patriotic worker to draw help and inspiration from his fellows had some counteracting effect, and might have made the meeting as large as previous ones but for the difficulties of traveling prevalent at the time.

PROFESSIONAL VISITS AND SOCIAL FEATURES

Subway Workings, Monday Afternoon, Feb. 18, 1918.—Mr. Robert Ridgway, Chief Engineer of the Public Service Commission, in collaboration with Prof. Robert M. Raymond, representative of the Institute,

arranged a most attractive mining trip to the new subway workings of New York City. Guides were furnished by the Engineering Department of the Public Service Commission, and every possible courtesy was extended. That portion of the new subway extending north from Broadway and Seventh Avenue to 50th Street is a four-track structure with all tracks on the same level, and its subgrade above mean high water. It passes directly beneath the present subway at Times Square; then connects with it at grade at about 44th Street. The new subway had to be constructed underneath the old subway without interrupting the traffic on the higher level, comprising nearly one thousand trains in 24 hr. or about 6569 cars carrying approximately one million passengers. The excavation is nearly all in rock, and great care had to be exercised in construction methods. The following approximate estimated quantities on this section are of interest:

Earth excavation	110,970 cu. yd.
Rock excavation	231,300 cu. yd.
Steel, including riveted steel and steel beams	5,310 tons
Concrete masonry	50,000 cu. yd.

After the inspection of this portion of the subway, the visitors proceeded to the Borough Hall Station in Brooklyn. At this point three timbered drifts are being driven by the poling-board method through sand and gravel, with no disturbance to overlying property, and timbered cuts to a depth of 80 ft. are being maintained without any loss of ground, although subjected to very heavy traffic conditions. The face of the drifts, above two cast-iron tubes already driven, is 23½ ft. wide and is breasted down with each advance. The timber sets carrying the polings are made of 12 by 12-in. timbers, spaced 4 ft. 4 in. on centers, with a distance between cap and sill of 6 ft. Hardwood blocks are used above and below the two center posts of each set and steel plates and wedges are placed between the posts and top hardwood block. By driving these wedges home the whole set is driven to a firm bearing, for not only is the sill settled, but all of the wedging in the bridge above the cap is crushed to full bearing under this initial loading. This operation prevents progressive settlement, which would otherwise take place by the load coming down gradually upon the poling-boards. The system of timbering had to be designed to take care of all the loads at proper intervals while the permanent structure is in course of erection.

Sketches and blue prints, together with literature fully explaining the methods used, were given to each member of the party and a most interesting visit was enjoyed by all who attended.

Visit to Art Galleries of Mr. Henry C. Frick, Monday Afternoon.—Through the courtesy of Mr. Henry C. Frick, more than 300 members and guests took advantage of the unusual opportunity of visiting his home, including the Art Galleries, containing many of world's great masterpieces in paintings as well as rare porcelains, books and other *objets d'art* of great charm.

Visit to Art Galleries of Hon. W. A. Clark, Monday Afternoon.—Senator Clark, who has so courteously entertained members of the Institute at his house on previous occasions, extended the same privileges for the 116th meeting, including a visit to his Art Galleries and the main rooms of his house. Besides the paintings, which are justly famous, rugs, furniture and other objects of great beauty and artistic merit

were seen. An organ recital was rendered on the famous pipe organ, and refreshments were served.

Luncheon.—On each day of the meeting, luncheon was served as usual on the fifth floor of the Engineering Societies Building, through the courtesy of the New York members of the Institute.

Motion-Picture Views of Bolivian Tin Mines, Tuesday Afternoon.—Mark R. Lamb gave a most interesting description of Bolivian tin mines, illustrated by motion-picture views and colored lantern slides.

Reception at Residence of President-Elect and Mrs. Sidney J. Jennings, Tuesday Afternoon.—The hospitality of President-elect and Mrs. Jennings was a feature of the meeting especially enjoyed and appreciated by the members and guests, adding a touch of personal element to the entertainment features of the meeting. Previous to this reception the visiting ladies were taken on a trip to the Metropolitan Museum of Art where they were met and guided around the Museum by one of the Instructors.

War Smoker, Tuesday Evening.—This patriotic meeting is described in detail on pages xxiv to xxxvi of this volume.

President's Reception, Wednesday Evening.—The reception of the retiring and incoming Presidents, with their wives, was organized under a committee of which Mr. John V. N. Dorr was Chairman. This differed from similar receptions of recent years in that an opportunity was given to each of the members and guests personally to greet the Presidents. The reception was held at the Hotel Biltmore immediately preceding the Annual Dinner.

"Hoover" Dinner, Wednesday Evening.—In accordance with the spirit of the times, the annual dinner was arranged with the approval of the Food Administrator and the following greeting, written for the occasion, was printed on the menu:

United States Food Administration,
Washington, D. C.
February 8, 1918.

Mr. Bradley Stoughton,
American Institute of Mining Engineers,
29 West 39th Street, New York City.

My Dear Stoughton:

I am glad to hear that the Conservation Division of the Food Administration is to dine in spirit with the American Institute of Mining Engineers. Be cheerful about this dinner; every year the War goes on, the butter pot will shrink in size—but it has disappeared in Germany. Some year or other, when we are living on the present German ration—they will crack.

Faithfully yours,
Herbert Hoover.

Orchestral music and a soloist were provided, patriotic songs being sung at intervals during the dinner. Short addresses were made by the retiring President, who also acted as toastmaster, by the incoming President, by Mr. Bainbridge Colby, Director of the U. S. Shipping Board, by Capt. Paul E. Dulieux, Head of the Engineering Service of the French Purchasing Commission, and by W. O. Hotchkiss, Secretary of the Association of American State Geologists, and member of the War Minerals Committee. Following the dinner, many of the members and guests lingered an hour or more for informal conversation, while some took advantage of the opportunity offered to engage in dancing.

Visit to Princeton, Thursday.—A party of about 150 persons left the Pennsylvania Station at 9:26 Thursday morning and proceeded to Princeton, N. J., where they were met by a Princeton Committee consisting of Dean H. B. Fine, Chairman, Dean McClenahan, Prof. Constant, and Prof. Scott. A walk through the beautiful grounds of the University brought the party to the Cleveland Memorial Tower and Proctor Hall of the Graduates' College. Here luncheon was served, an organ recital being rendered meanwhile. Following this, two most inspiring addresses were made, one by Dr. John Grier Hibben, President of Princeton University, and a response by President Philip N. Moore. The party then proceeded to the Ground Aviation School in the University Laboratories. Only those were admitted who were citizens of the United States or its Allies, and many interesting details of the instruction of aviators were explained to the visitors. After visiting several of the University buildings, the party assembled in Nassau Hall, where Mr. Moses Taylor Pyne, a Trustee of Princeton, gave an interesting historical address upon the part played by Nassau Hall in the history of the United States. The party then entrained for New York. The arrangements at Princeton were under the direction of Mr. Knox Taylor, and were warmly appreciated by those who attended.

Woman's Auxiliary and Entertainment of Ladies

The ladies took part in the social features mentioned above, except the War Smoker, especially enjoying the visit to the art galleries, the reception of President-elect and Mrs. Jennings, the Presidents' Reception, the Annual Dinner and the visit to Princeton. In addition to these activities, the Woman's Auxiliary held business meetings on the mornings of Tuesday and Wednesday, and arranged two lectures in the Auditorium. At the Wednesday morning lecture, Dr. Vernon Kellogg spoke on behalf of the U. S. Food Administration. On Tuesday afternoon, an address, illustrated by motion pictures and lantern slides, of the work of the Civilian Committee in the devastated district of Northern France, was given by Mrs. Needham, representing the American Fund for French Wounded.

A matinée at the Century Theatre was also arranged for the ladies through the courtesy of the New York members, to see Chu Chin Chow. Many ladies attended the luncheon each day, and the visit to Princeton.

Annual Business Meeting of the Institute

The annual meeting of the Institute, for the transaction of business, was called to order by President Moore at 10 a.m. on Tuesday, Feb. 19, 1918, the second day of the 116th Meeting.

The Secretary testified that a quorum was present.

On motion of Mr. Geo. C. Stone, the minutes of the previous annual meeting, Feb. 20, 1917 (printed in *Trans.*, **56,** xvii) were approved. President Moore then delivered an admirable address (printed in this volume, p. xl) emphasizing particularly the desirability of promoting the activities of local sections, and reporting on the numerous lines of work undertaken by the Institute and its members to assist in the conduct of the war.

The report of the Treasurer was accepted.

The report of the Secretary was accepted.

The report of tellers on election of officers and directors was read by the Secretary. Whereupon the President declared the following to be elected:

Director and President, Sidney J. Jennings
Director and Vice-President, Henry S. Drinker
Director and Vice-President, Robert M. Raymond
Director, District 6........Frederick G. Cottrell
Director, District 9........Hennen Jennings
Director, District 0........George C. Stone
Director, District 2........Samuel A. Taylor
Director, District 3........Arthur Thacher

The report of the tellers on the proposed amendment to Art. II, Sec. 2, of the constitution reported as follows: in favor of the amendment, 1123 votes; opposed to the amendment, 59 votes.

On motion of Dr. A. L. Ledoux, a vote of thanks was given to the tellers, who had devoted a great deal of time and strength to their labors.

Reports of the Library Committee, of the Committee on Publications, and of the Committees on Membership and Increase of Membership were accepted as printed.

There being no miscellaneous business, the annual meeting then adjourned. Bradley Stoughton, *Secretary.*

Technical Sessions

Session on Coal

The session on coal was held on Monday morning, Feb. 18, 1918, Mr. Edwin Ludlow presiding. The following papers were presented:

The Drifton Breaker. By E. P. Humphrey. (Presented by title.)

The Economy of Electricity Over Steam for Power Purposes in and about the Mines. By R. E. Hobart. (Presented by author and discussed by Karl A. Pauly, Graham Bright, W. H. Blauvelt, H. M. Crankshaw, Eli T. Conner.)

The Briquetting of Anthracite Coal. By W. P. Frey. (Presented by author and discussed by Burke Baker, Arthur H. Storrs, Felix A. Vogel, J. B. McGraw.)

Heating of Coal in Piles. By C. M. Young. (Presented by title.)

Review of the Coal Situation of the World. By G. S. Rice. (Presented by author and discussed by Edwin Ludlow and W. H. Blauvelt.)

Pen-hsi-hu Coal and Iron Co., South Manchuria, China. By C. F. Wang. (Presented by T. T. Read and discussed by Edwin Ludlow, T. T. Read, J. E. Johnson, Jr.)

Session on Non-ferrous Metallurgy

The session on non-ferrous metallurgy was held on Monday morning, Feb. 18, 1918, G. H. Clevenger presiding. The following papers were presented:

Notes on the Disadvantages of Chrome Brick in Copper Reverberatory Furnaces. By F. R. Pyne. (Presented by author and discussed by G. H. Clevenger, H. O. Hofman, Forest Rutherford, Bradley Stoughton.)

Fine-grinding and Porous-briquetting of the Zinc Charge. By W. McA. Johnson. (Presented by author and discussed by O. C. Ralston, C. A. H. de Saulles, R. H. Eagles, and the author.)

High-temperature Resistance Furnaces with Ductile Molybdenum or Tungsten Resistors. By W. E. Ruder. (Presented by author and discussed by R. G. Hall and the author.)

Zinc Refining. By L. E. Wemple. (Presented by author and discussed by E. Gybbon Spilsbury, W. McA. Johnson, and the author.)

Bone-ash Cupels. By F. P. Dewey. (Presented by title.)

An Automatic Filter at Depue, Ill. By G. S. Brooks and L. G. Duncan. (Presented by title.)

Session on Mining and Milling

The session on mining and milling was held on Tuesday morning, Feb. 19, 1918, immediately after the Annual Meeting of the Institute, Sidney J. Jennings presiding. The following papers were presented:

Some Practical Hints on Bucket-elevator Operation. By A. M. Nicholas. (Pre sented by author.)

Recent Tests of Ball-mill Crushing. By Charles T. Van Winkle. (Presented by title and discussed by John W. Bell, J. Parke Channing, B. Britton Gottsberger, H. W. Hardinge, E. H. Kennard, Albert E. Wiggin.)

Notes on Theory and Practice of Ball-milling, Particularly Peripheral Discharge Mills. By Pierre R. Hines. (Presented by title.)

A New Method of Separating Materials of Different Specific Gravities. By Thomas M. Chance. (Presented on behalf of the author and discussed by H. M. Chance.)

The United Eastern Mining and Milling Plant. By Otto Wartenweiler. (Presented by title and discussed by John B. Hastings.)

Otis Passenger Elevator at Inspiration Shaft. By C. E. Arnold. (Presented by title.)

Branch Raise System at the Ruth Mine, Nevada. By Walter S. Larsh. (Presented by title.)

Incline Top-slicing Method. By W. G. Scott. (Presented by title and discussed by C. A. Mitke.)

Canvas Tubing for Mine Ventilation. By L. D. Frink. (Presented by title.)

Measures for Controlling Fires at the Copper Queen Mine. By Gerald Sherman. Presented by title and discussed by R. E. Tally.)

Session on Iron and Steel

The session on iron and steel was held on Tuesday afternoon, Feb. 19, 1918, Prof. J. W. Richards presiding. The following papers were presented:

The Erosion of Guns. By H. M. Howe. (Presented by Hudson Maxim and discussed by Rear Admiral Ralph Earle and Lieutenant-Commander N. W. Pickering, Henry D. Hibbard, J. S. Unger, C. I. B. Henning, James E. Howard, Francis I. du Pont, Zay Jeffries, Henry Fay, F. N. Speller, Henry R. Batcheller, W. P. Barba, E. D. Campbell.)

Transverse Fissures in Steel Rails. By J. E. Howard. (Presented by title and discussed by H. D. Hibbard, C. W. Gennet, Jr., John D. Isaacs, Robert Trimble, F. A. Weymouth, J. S. Unger, P. H. Dudley, G. J. Ray, A. W. Gibbs, W. R. Webster, M. H. Wickhorst, Robert Job.)

Temperature-viscosity Relations in the Ternary System $CaO–Al_2O_3–SiO_2$. By A. L. Feild and P. H. Royster. (Presented by title.)

Slag Viscosity Tables for Blast Furnace Work. By A. L. Feild and P. H. Royster. (Presented by title and discussed by D. J. Demorest, F. H. Willcox.)

Session on Petroleum and Gas

The session on petroleum and gas was held on Tuesday afternoon, Feb. 19, 1918, A. F. Lucas presiding. The following papers were presented:

The Possibilities of Oil and Gas Fields in the Cretaceous Beds of Alabama. By Dorsey Hager. (Presented by title and discussed by E. DeGolyer and I. N. Knapp.)

Principles and Problems of Oil Prospecting in the Gulf Coast Country. By W. G, Matteson. (Presented by author and discussed by A. F. Lucas, E. Sherburne Rogers, E. W. Shaw, Eugene Coste, Chester W. Washburne, Kirby Thomas, and the author.)

Some New Methods for Estimating the Future Production of Oil Wells. By Carl H. Beal and J. O. Lewis. (Presented by Carl H. Beal and discussed by Roswell H. Johnson.)

Methods of Valuing Oil Lands. By M. L. Requa. (Presented by Chester W. Washburne and discussed by F. G. Clapp, and W. N. Best.)

Water Surfaces in the Oil Fields. By M. R. Daly. (Presented by title.)

Age of the Oil in Southern Oklahoma Fields. By Sidney Powers. (Presented by title and discussed by W. E. Pratt and W. G. Matteson.)

Extraction of Gasolene from Natural Gas. By F. P. Peterson. (Presented by title.)

Sessions on Employment Problems

The first session on employment problems was held on Wednesday morning, Feb. 20, 1918, Charles W. Goodale presiding. The following papers were presented:

Mine Labor and Accidents. By H. M. Wilson. (Presented by author and discussed by H. N. Eavenson, B. F. Tillson, E. E. Bach, C. W. Goodale, T. T. Read, George S. Rice, and the author.)

Illness in Industry—Its Cost and Prevention. By Dr. Thomas Darlington. (Presented by title and discussed by Dr. E. E. Southard.)

The Employment Manager and Labor Turnover Reduction. By Thomas T. Read. (Presented by author and discussed by E. E. Bach, C. R. Hook.)

The second session on employment problems was held on Wednesday afternoon, Feb. 20, 1918, T. T. Read presiding. The following papers were presented:

Social and Religious Organizations as Factors in the Labor Problem. By E. E. Bach. (Presented by author and discussed by Sidney Rolle, R. H. Vail, Martin L. Griffin, C. W. Goodale, Shelby Harrison, L. E. Reber, R. M. Catlin, George S. Rice, Lawrence Veiller, and the author.)

Training Workmen for Positions of Higher Responsibility. By F. C. Stanford. (Presented by B. A. Robinson and discussed by E. E. Bach, F. C. Henderschott, Sidney Rolle, John B. Hastings).

Getting the Foreign Workman's Viewpoint. By Lazarovich Hrebilianovich. (Presented by author.)

The Crippled Soldier in Industry. By Major Frank M. Gilbreth. (Presented by Mrs. Frank B. Gilbreth and discussed by Bradley Stoughton, L. D. Huntoon, J. M. Glenn, W. M. Kreglow, C. R. Hook, E. E. Bach, Richard Lamb, Martin L. Griffin.)

Session on Metallography of Steel

The session on metallography of steel was held on Wednesday morning, Feb. 20, 1918, E. Gybbon Spilsbury presiding. The following papers were presented:

Grain Size Inheritance in Iron and Carbon Steel. By Zay Jeffries. (Presented by author and discussed by W. E. Ruder, and the author.)

The Time Effect in Tempering Steel. By Capt. A. E. Bellis. (Presented by title and discussed by H. M. Boylston, J. A. Mathews, Carle R. Hayward.)

Some Structures in Steel Fusion Welds. By S. W. Miller. (Presented by the author and discussed by H. M. Boylston, W. E. Ruder, Zay Jeffries.)

The Effect of the Presence of a Small Amount of Copper in Medium-carbon Steel. By Carle R. Hayward and Archibald B. Johnston. (Presented by title and discussed by Frank N. Speller, E. F. Cone, J. A. Mathews.)

Session on Geology and Ore Deposits

The session on geology and ore deposits was held on Wednesday afternoon, Feb. 20, 1918, Sidney H. Ball presiding. The following papers were presented:

The Chilean Nitrate Industry. By Allen H. Rogers and Hugh R. Van Wagenen. (Presented by A. H. Rogers and discussed by Fred MacCoy, J. T. Singewald, Jr., Waldemar Lindgren.)

Genesis of the Sudbury Nickel-copper Ores as Indicated by Recent Exploration. By Hugh M. Roberts and R. D. Longyear. (Presented by H. M. Roberts and discussed by George F. Kunz, Frank F. Grout, W. G. Miller, A. M. Bateman, Charles P. Berkey, Waldemar Lindgren, L. C. Graton.)

The Relation of Sphalerite to Other Sulphides in Ores. By L. P. Teas. (Presented by C. P. Berkey and discussed by Thomas L. Watson, L. C. Graton.)

Pyrite and Pyrrhotite Resources of Ducktown, Tennessee. By Joseph H. Taylor. (Presented by title.)

Ore Deposits of the Yellow Pine Mining District. By Fred A. Hale, Jr. (Presented by title.)

Phosphate in Egypt. By E. Cortese. (Presented by title.)

The Wisconsin Zinc District. By H. C. George. (Presented by title and discussed by W. O. Hotchkiss, W. N. Smith.)

WAR SMOKER

The Chairman (Dr. A. R. Ledoux).—If there ever was a question in the mind of anybody as to whether there are some mining engineers, I think if they would look in the door tonight they would decide there are. We meet here tonight not only to enjoy a smoke and other incidentals which are permitted us in these days, but with a more serious thought in our minds, because that flag, with its 540 stars, only begins to show the number of our membership that are serving the country. We are thinking of them, and when we consider how many of those men are also citizens of one or another of our allied countries, we can imagine that many are tonight thinking of us and perhaps have received, even at the front, notices of our annual meeting and are wondering what we are doing tonight; so our thought this evening will be going out to them, going out to those of our number who are serving in the khaki or in the blue, or in other activities denied to some of us for one reason or another; but, gentlemen, there is one thing we will do now, we will rise and sing together the Star Spangled Banner.

Gentlemen, not only are American citizens here tonight, not only representatives of our country on the Speakers' platform, but there are representatives of our Allies, and we are going to have the privilege of listening to one or two of the latter, a citizen of the great British Empire and a citizen of France. We will first have the pleasure of hearing Capt. Hodder-Williams. He has been loaned to us to take charge of training Columbia University students, after two years or more in the trenches, and he carries with him the only German thing in this room, a German bullet in his shoulder. That has not affected either his spirit or his

heart or his power of speech, as I am sure you will agree when you have heard him.

CAPT. R. HODDER-WILLIAMS.—There are two advantages in speaking first: one is that, when it is all over, you can enjoy your pipe, and the other is it gives me a chance to get off my only story. This story is told of the very early days of the war, when Kitchener's original 100,000 were training hard in England, and they were getting all sorts of funny people into the ranks. In one battalion of a London regiment, there happened to be a large number of stock exchange men, men of about 30 years. These fellows, of course, didn't know anything about army discipline and cared less, and the first few days they were having a great time, but they were pulled up with rather a rude shock when they received, as new company commander, a boy of 18 who had been given a commission when the war broke out. He had rushed into France, been wounded at the Marne, returned to England, and very shortly was back training one of these new battalions. He had gone out as a second lieutenant, but as he had had some war experience, they made him a captain, and this boy proceeded to give them general hell all around, and they didn't altogether like it. So, after a time they hit upon a little phrase which they took from a well known book, well known even to stock exchange men; the phrase was "a little child shall lead them," and this phrase went up and down the ranks all day long. They sang it as they marched, and passed it up and down the line, "a little child shall lead them," and the officer took no notice of it at all. In the afternoon, on parade, again this refrain went up and down the line, "a little child shall lead them." Still the officer took no notice. It went on until the end of the day. At five o'clock he called them to attention and announced, "Training for tomorrow; there will be a route march; it will be a very long route march; we shall go 26 miles; we shall go in full marching order and we shall carry rifles; we shall carry ammunition; we shall carry everything we shall need; it is going to be very hot and we are going 26 miles; and a little child shall lead them—on a horse."

You will perhaps be a little surprised to know that I feel as one fallen among thieves. The infantry man regards the mining engineer with all the loathing that is to be expected of him, considering their relative duties in the front line. Of course all engineers—sappers, as we call them in the British Army—are a confounded nuisance to the infantrymen anyway. They come and tell us what to do and then leave us to do it; but the worst of all is the mining engineer; he has become a tunneling company out there, and if there is anything worse than a tunneling company, I want to see it.

The tunneling company works under ground, but something has to come out of the tunnel. Do the tunneling companies take their earth away? Oh, no! That, according to the tunneling companies, is exactly what the infantry are for. The earth comes out in sand bags; it is heavy and wet, and you may leave it there, but if you do, one of several things will happen; in the first place, it will stay there because it can't move itself; in the second place, it is sure to block up the trench because the tunneling company waits on no man; in the third place, the sand bags will come over the top of the parapet and the accumulation will be duly noticed by our friends on the other side, and having noticed it, they will duly proceed to demolish the sand bags—all very nice for the tunneling company, 40 or 50 ft. under ground, but pretty rotten for the infantry;

so you see, of two evils the lesser is to take their beastly sand bags and clear them away, which takes a long time and is hard work; so I hate all mining engineers.

I wish to say a few words a little more seriously. There is only one thing that counts in the soldier's life in this war, as in any other, and that is discipline. There is a lot of talk about not needing the German discipline. That is absolute buncombe; you must have just as good discipline as the Germans have before you can hope to win the war. There are various ways of getting discipline; we are after it in a different way from theirs. So far as possible, we try to make men understand the whole principle of self discipline, but do not, for a moment, think you can succeed in this war with less discipline because you come from North America. The only thing that will happen to you, if you have less discipline, is that you will get killed. The only way you can possibly hope to win the war is to have discipline at least as good as the Germans. I have a perfectly good reason to dislike the Germans, but they have a superb discipline, and that discipline extends far beyond the army. The very fact that all this fuss was made over the first real strike they had a few weeks ago, and the speed at which it was put down, is sufficient proof that the German people are disciplined.

It is extraordinarily common over here to hear people say, "We are all in it, this is a people's war," etc. It rather reminds you of Robert Louis Stevenson's phrase, "A man should not live on bread alone, but principally on catch words." A good many of us are inclined to live on catch words. Do we realize just what being a people's war means? It means that the American people have got to discipline themselves and not leave all the discipline to the soldiers. You cannot begin to win this war until you have all America fighting all Germany. Don't ask American soldiers and American sailors to fight the German people; they can't do it. We will look after the German army, but it is up to you to help look after the German people. The German people, whether willingly or not, are mobilized against us; are the American people mobilized against the German? The vital importance of discipline everywhere I think is beginning to be felt, but rather slowly. Of course you can imagine that labor strikes make a soldier pretty mad; when soldiers go on strike, we get shot for it. There is lack of discipline in Canada as well as in the United States and in other quarters, and in other walks of life and in other professions besides labor; and the question is whether the people are going to settle down to the disciplining of themselves, without which the winning of the war is absolutely hopeless.

What is discipline, gentlemen? It is something the outward and visible sign of which may be saluting, and a smart uniform, and obeying orders, and so on; but its inward grace, more important than that, enables us to stick at things whether they are pleasure or not, and not to count the cost. It may seem easy, in the excitement of battle, to forget the cost, but it is not easy, because you see what is going on. The time comes to almost everybody as it came to me on the 15th of September, 1916, to realize, if you are a leader, that all that you have to do, all that you have been doing through the gruelling of the last 2 or 3 years, is going to depend absolutely on the discipline of those men behind you. As we went forward, everybody was having a great time; suddenly we were absolutely at the mercy of the German machine guns, and there was nothing to do but to rush them. Can you imagine the feelings of a man

as he goes ahead to lead his men forward, who knows without ever turning his head, without ever hearing or seeing a man, that those men are right behind him, trying to get in front of him all the time, to get at that machine gun? That is discipline. We got the machine gun, and the price we paid was perfectly terrible, but it is being paid all the time. If I have any message to give you, gentlemen in a profession in which I imagine discipline counts a great deal, it is just to ask you to spread the gospel of discipline outside the army.

The Chairman.—Many good Americans, like myself, came to America by way of Canada. We shall now have the pleasure of listening to a Frenchman who came to us by way of Canada, representing the French government officially, as head of the engineering branch of the French Purchasing Commission.

Capt. P. E. Dulieux.—I trust you do not expect from me a humorous and interesting speech like the previous one. I am not speaking in my own language and I am entirely unprepared, but what I can express is the deep feeling of sympathy which is around me today, which we have found to increase daily since the entrance of America into the war.

After a third winter, France was thinking of the end of the war, and did not see the end of it. I dare not to say that France was exhausted, but our fighting men in the trenches and our civilian population were looking across to the other side of the ocean, to our great sister Republic, and wondering why this great country of freedom did not come, did not join us in this great fight. Now you have come, and from now on our spirit rises. In France the wavering spirit which was noticeable in June of last year has entirely disappeared, and now we are more united than before and we count more than before on the Americans.

When I see such a gathering as this, when I see the representatives of so large an industry as mining eager to coöperate, eager to find a way to help, it is a great comfort to me; but the task before us is very great, it is immense. The Germans are still in France, they are still in possession of the richest part of our country.

In such distressing times, we have a song more than a hundred years old, which has ever inspired our French people, a song which helped us to repulse the Huns and the Germans, more than a hundred years ago, a song that only the free countries of the world are allowed to sing, which I beg of you to join with me in singing.

(The Marseillaise was sung in French.)

The Chairman.—On the front page of the *Tribune* today was what purported to be an up-to-date picture of the City of Washington, composed of nothing but Bureaus, running from the foreground back into the far distance. The very first one is Bureau 113 of the War Department, and it is intimated that while we used to speak of Bureaucracy, the present pronunciation is Bureaucrazy.

Even the mining engineers have had something to do with some of the Bureaus, if only to straighten out some of the tangles and unwind some of the red tape. Representatives of some of those Bureaus are here this evening and have kindly consented to tell us something of their work. First I shall call on Mr. S. A. Taylor, of the Fuel Administration.

S. A. Taylor.—In August of 1914, I was in Canada when this fateful struggle of the world took place, and one of my Canadian friends asked me, "What will the United States do in case Germany should attack Canada?" I replied: "The United States will have to do one of two things: either disregard and discard the Monroe Doctrine, or they will come to your rescue; and I think it will be the latter." Whether this was a proper diagnosis of the question or not, at any rate we are today engaged in this titanic struggle, as has been tersely said, to make the world safe for democracy. But I believe, gentlemen, that when this war is over the greatest problem that will confront us will be to make democracy safe for the world. And I believe that this problem will call for the highest intelligence of such men as are here tonight.

The Fuel Administration has received some encomiums in the paper that I presume I need not speak about, but to get a little clearer idea of the work of the Fuel Administration, it may be well to look at the situation as it confronted the American people.

Throughout the United States the coal business was used practically as a football. In that famous paper which he read before the American Mining Congress, in Philadelphia, in October, 1913, E. W. Parker gives some very significant figures, of which I will quote only a few.

The figures on anthracite coal, taken from the census of 1910, showed that anthracite producers earned only 4 per cent. on their capitalization, after allowing less than 5 c. a ton for amortization charges against the entire property investment in that great industry. In the bituminous coal industry of the country, while the production was over 400,000,000 tons, the amount received for it was $401,000,000. In round figures, the amount that was given over to capital or set aside for capital was 2½ per cent. without allowing anything for amortization.

We might dwell for a moment on the railroad situation, because at no time in the history of the coal business has it been lack of coal that caused the trouble. The trouble here this winter has been a transportation problem, pure and simple; yet we cannot blame the railroads entirely, we must take part of that blame ourselves. We have harassed and embarrassed the railroads of this country until they were not able to purchase the necessary rolling stock to move the materials offered to them. They lacked terminal facilities, railroad cars, and above all, locomotives, and these could not be purchased on promises of future higher rates. The Interstate Commerce Commission, with the Sherman Act, has done a damage to this country that is almost irreparable. I know that this is not popular doctrine, but I believe it is susceptible of proof; and until this country deals more favorably with railroads than it has in the past decade, we shall continue to experience great difficulty in transportation, not only of coal but of a number of other essential things.

Early in 1917, contracts had been made in a number of cases at very low prices, and while those who had not made contracts were generally paying a fabulous price for coal, very little of it reached the coal operators, but was passing into the hands of a middleman and stopping there. This led to the establishment of a Coal Committee under the War Industries' Board, with Mr. Francis Peabody at its head. He gathered around him a coterie of coal operators, better than whom there are none, men who understand the business thoroughly, and at the instance of Secretary Lane, he called the operators of this entire country together at a

meeting in Washington and they fixed a price for coal throughout the country. As these prices were not wholly satisfactory, the result was the introduction, by Senator Pomerene, of an amendment to the Food Law, commonly known as the Lever Act, which called for the appointment of a Fuel Administrator. This act was passed, and Dr. Harry A. Garfield was appointed Fuel Administrator.

I know that the public generally has given Dr. Garfield a great deal of criticism, but I wish to say that I have never met a fairer minded man than Dr. Garfield. He is a man of exceptional ability, good judgment, and possesses so many manly qualities, as well as educational qualifications, that no one can come in contact with him without having dispelled all feelings of distrust which one may have acquired through newspaper criticism of him. He possesses that rare quality of being able to decline granting requests and at the same time to send those who make them away with the feeling that he is eminently fair, which is no small qualification for a man who must fill the position of Fuel Administrator of this country.

I was asked to speak about the work I am doing in Washington with Dr. Garfield. I have the euphonious title of Engineer and Technical Advisor, if you know what that means; under that title most everything that comes into the office could be relegated to me. Some of the things I have had to do have been to compile data as to the amount of coal that we should need, keep in touch with the Geological Survey's weekly reports, and make prognostications as to the future. Early in October, when we saw was what coming on, Dr. Garfield's Board of Advisers, consisting at that time of Mr. Rembrant Field, Mr. John White, and myself, advised him to ask for an unlimited car supply. For some reason his request was not granted, and I think that therein lies the real cause of the upset that arrived a few months ago. Had the railroads been sufficiently urged, or had they been in position to grant the request of Dr. Garfield, I am perfectly satisfied that we could have gone through this winter without any difficulty.

It has frequently been asked whether we have enough mines or enough men in this country to produce the necessary coal. I can answer positively that we have. My estimates clearly showed that we can produce about 700,000,000 tons of bituminous coal in a year, providing the mines were given full and regular car supply. There has been a considerable shortage of men in the coal mines, but this has not been so largely due to taking the men for the army as has been stated; in the first draft, only 18,000 men were taken out of the mines.

Another of my duties is to estimate our needs for this year. Every week I make an estimate for Dr. Garfield, showing what has been accomplished the week before and how much we are falling behind on what we expect to need for the coming year.

Another matter had to do with the Northwest, which gets its coal by way of the Lakes in the summer. When prices were fixed, it looked as though either the Northwest were going to suffer a great shortage of coal, or the dock operators in the Northwest were going to suffer bankruptcy; this involved a nice piece of constructive work on which I am sure almost any engineer would be glad to work. Our dock manager came down from the Northwest and brought with him every contract of every dock in that region. Those were tabulated, not only as to prices but as to freight rates both on the railroad and on the lake; each

dock was separately studied in that way. Those docks that are equipped with modern machinery involve a tremendous investment as compared with some of the older docks with cheaper machinery; but the cost per ton for operating the newer docks was less than 2 per cent. below that of the older, taking into account the depreciation on the investment. A price was therefore fixed for coal going to the Northwest that gave the dock owner 50 c. profit and insured to all the Northwest all the coal they needed.

Another interesting question is this recently proposed zoning system, which is not yet quite ready to put into effect. Knowing that the trouble lies almost entirely with traffic, the idea of the zoning system is to reduce the amount of cross-haul, and let each district get its coal from the nearest producing center. The whole country was therefore divided into 11 consuming districts and 20 producing districts. These were so arranged that, as far as possible, each consuming district would be self-contained; that is, it would produce enough coal to take care of its own consumption. This takes considerable time, because we first have to ascertain the kind and amount of coal that each district requires, and then determine where that coal can be obtained. Two special requirements had to be eliminated from the calculations; namely, coal for gas works and coal for the byproduct coke plants. Aside from those industries, I think we are working out a system of distribution which, after the war is over, ought to be of great value to the entire railroad system of this country.

The Chairman.—In order to dispose of the subject of fuel, I will ask Mr. Requa, head of the Oil Division of the Fuel Administration, to tell us something of his work.

M. L. Requa.—Since early in June, 1917, I have been in Washington with the Food Administration, serving under Mr. Hoover, and for about a month in the Fuel Administration, in charge of the Oil Division. Because of the fact that for five or six years I have amused myself with the study of governmental organization, it has been intensely interesting to me to follow the course of events in Washington. Perhaps I have been more fortunate than some of the volunteers, in being more or less familiar with the history of similar efforts in the past. Washington has tried almost every experiment of democracy, so far as governmental organization is concerned, and many of them have been proved unsatisfactory a great many times over in the history of this nation; but notwithstanding that, they have been tried again in Washington. Now I am glad to say that we are making progress, probably as fast as can be expected, all things considered. The rigid departmental system existing in Washington has not made it possible to attain, through the existing departments, the results that we must secure if we are to win this war; and superimposed upon those departments has been a series of emergency departments created for the purpose of meeting the present crisis.

Democracy has always been fearful of entrusting any great amount of responsibility and initiative to the individual, but has set up a system of checks and balances and permitted only those things to be done that were specifically provided for. The theory that I believe should have been followed was to permit officials to do anything except what was specifically prohibited. I believe that the President of the United States, under the existing conditions, should be given absolute and complete

power to do whatever is necessary to win this war. If democracy, in time of stress, cannot surrender its initiative, and cannot forego individual liberty, and subject itself to the rigid discipline that characterizes autocracy, I believe that the ultimate decision will be that democracy is a failure. When the crisis has passed, we must, of course, restore the rights of individual effort, we must permit the greatest amount of individual initiative, and must give full freedom to the right of the individual to carry on his own vocation in his own way. But this is no time for individual effort, it is emphatically a time for collective effort, and if we cannot make ourselves as efficient as an autocratic government, if we cannot voluntarily and freely do those things that are made mandatory by the edict of the German Empire, I believe that the nation and our form of government are in great danger.

We have advanced a great way, gentlemen, in the last few months, and I do not believe that we shall ever return to just where we were before the war began. We have seen the Sherman Anti-Trust Law smashed into a thousand pieces, under the operation of paragraph 2 of the Lever Act, which gives the President the right to make voluntary agreements with individuals or corporations, and gives permission to do almost anything that is necessary to be done.

Like almost all new measures, the Food Bill falls short of what it ought to be. Permission is given the Food Administration to fix profits, but it may not fix prices—that is, theoretically. As a matter of fact, I think it is a perfectly good price-fixing organization. When I was connected with it I lay awake nights scheming out ways to do some of the things I knew we ought to do and that were not exactly provided for in the bill. We recognized that no matter what control we had over the industry, if we let the last retail merchant run loose, that he would get away with the whole works. So I conceived a scheme one night which I sprung the next day upon the members of the Food Administration. We had the right, under Section 5, to put anybody under license and give him rules and regulations to operate by. It was not specified what those rules and regulations were to be. So I said, "We will give the wholesale grocers a regulation that they may not sell any groceries to any retailer who does not play the game," and I think it works.

I am firm in the belief that, if you are to regulate the price of food products, you have no valid defense when the farmer comes to you and says "Yes, that's all right, but what about the price of the shoes I wear, or the clothes I wear, or the farming machinery I have to buy?" That is the great problem in this whole situation. You cannot take a segment out of the circle of the industrial life of the United States, set it off by itself, call it the food industry, and regulate it, without giving some consideration to the regulation of other products. I am perfectly satisfied that every day that this war lasts brings us nearer to governmental regulation of a great many different things, not because we like to contemplate it but because there is apparently no other way out of the dilemma.

Consider the oil industry today. The problem, in a very few words, is this: we have three barrels of oil to deliver, and transportation facilities for only two. Because the oil marketing companies of this country were selling a large part of their oil under contract, it was impossible for them to differentiate between their various customers; so we saw the spectacle of the manufacturer of Liberty Motors or some vitally neces-

sary munition, getting exactly the same consideration and the same deliveries as the manufacturer of baby carriages, hat racks, or furniture. In an effort to correct that, a presidential proclamation was issued enumerating a series of classes into which the various industries consuming oil have been placed. Starting with railroads and bunker fuel as No. 1, and going on down the list, we come to plants engaged in the manufacture of munitions or other governmental supplies, which you will perhaps be surprised to learn are next to the last. We are now trying to deliver oil under that priority order.

There is plenty of oil to meet the needs of the situation, but there is a lack of transportation to move it. It is quite obvious that if the tank-car mileage of the United States drops from 36 miles, the average of 1917, to 6 miles in January, you are not going to deliver the oil; and if you take 40 per cent. of the ships out of the domestic trade and put them in the trans-Atlantic trade, I do not know any way to meet the situation, unless somebody goes without fuel oil, and it is in an endeavor to decide who can best go without it that we are now engaged in our examination of the entire oil industry.

The Chairman.—While today the name of Hoover makes us think of the dining room more than of anything else, it was but a short time ago that, when we said Hoover, we thought of Belgian relief. Mr. Hoover cannot be with us tonight, and if he were here he probably would prefer to talk about our duty in the line of conservation, but Mr. Honnold is here, his right-hand man in the Belgian Relief, whom I will ask to speak.

W. N. Honnold.—The situation of Belgian Relief is this; we are going along quietly, thanks to the fact that our funds for some time past have been provided from government sources, but because of difficulties which bear on every line of war activity, we have found it impossible to live up to our program. In fact, during the last 6 months we have been able to deliver only about 60 per cent. of what was considered the minimum required in Belgium and Northern France. In recent months, notwithstanding these limitations, our expenditure has been in the neighborhood of $30,000,000; and up to date, the total expenditure on the relief work is in the neighborhood of $400,000,000. At the end of 1917, about half of the total, that is, about $180,000,000, had been provided by France, partly for relief in Northern France and partly as an advance to Belgium; $91,000,000 had been provided by England, and approximately the same amount by America. The tendency now is for the American proportion to increase.

Our activities are mainly of a commercial nature now, but we have reached a stage at which we are obliged to put out an appeal. That appeal is for clothing. The position in Belgium and Northern France is extremely precarious as to wearing apparel, boots and shoes. The Germans have requisitioned 80 per cent. of all stocks of such commodities that remain in the country; they have requisitioned all wool mattresses and have practically laid their hands on everything except personal apparel which, as yet, has not been disturbed, and so far there has been no disposition to interfere with such clothing as we have sent into the country. We had secured an authorization from the British Government to purchase some $11,000,000 worth of clothing to meet the needs for the coming season, but when we had dealt with about 40 per cent. of that order and were just beginning to make an impression on the situation,

the British found that the stocks in their country were getting so low and that the needs of the army and of their own people for wool were so extreme, that they were obliged to withdraw that permission. The position here in America is very much the same as to wool; there is a genuine shortage in the world today.

As to the position in Belgium, we are able to hear through certain diplomatic channels and individuals that the situation daily grows more serious. The strain on the morale of the people is very severe. It is difficult, in fact impossible, for anyone who has not been in Belgium to realize what it means to a people to be between a barbed-wire fence on the north and the German army on the south.

They have no communication with the outside world. I talked time after time with mothers, fathers, sisters and brothers who had relatives with the Belgian army, which went out with the King in the early days, and they had never had a word from them. It is a horrible situation; they have no idea what is happening. Internally a similar condition exists; it is impossible to carry on any correspondence. Letter writing is out of the question; people in one community, except through some surreptitious method, know practically nothing of what is going on in another, and all of these conditions tend to create an atmosphere of dread, of uncertainty as to what is happening. The saving feature is that there is always a hopeful attitude. You never talk with a Belgian who is not optimistic.

In addition to the nightmare which prevails through this isolation, there is a nightmare of uncertainty as to food. We have never been able to make good as to our full program, and sometimes stocks ran very low; the word is whispered about, and that of course sets up a period of uncertainty in the minds of the people. Our contributions, if we were able to live up to our program, would only be equivalent to 1000 calories per capita per day; I doubt whether we get in much more than 750 calories. As you know, 2400 to 3000 calories is considered necessary for a normal person. In addition to this small amount of food we are able to send in, there is the local supply, which is estimated to provide about 750 calories; but, at best, there is only about half a ration for the people of the country. It is a horrible situation. The marvel is that there has not been more suffering, and that is largely because of the special care which has been given to cases which call for special attention. At the very beginning, the Belgian people organized themselves under a head, the so-called Comité National. That organization includes some 40,000 people, the leading citizens of every community being on the communal and district committees. The same condition prevails in northern France, where some 22,000 people are still giving all their time to relief work. The outstanding impression one carries away from the country is the wonderfully self-sacrificing attitude of these people who are giving their time to relief work.

As to our own organization, as to the 130 men who were in Belgium with us, about three-quarters of them are still in service in one form or another. Over one-third are in military service; 34 are in the American army, 3 are in the American navy; one is in the Belgian army; there are several in the French army, and six in the British army. Others are on Red Cross work, ambulance driving, Y. M. C. A. work, and all going on in the same spirit in which they entered this work at the first. Those young men were specially selected with a view to their even balance of

temperament; all of them insisted they were neutral when they went in, and yet when they came out, every one of them has felt that he simply had to go on and do something more active.

Those men not only came in touch with the frightful effects of the war measures of the Germans, but they came into touch with the German from the standpoint of his capacity, and you cannot do that without having a respect for them as a fighting people. They are superior men; they give the impression of thinking of nothing but their job, and certainly no one of our men ever makes slighting remarks of the German as an enemy. Every one of our men has the impression that the war is going to be a long war, and that is the impression we must get here. This is a fight that cannot be escaped, it has got to be gone through with. There is no such thing as peace talk at this stage; it is a poisonous idea; unless we win this war, the other side is going to win, and then there will be no mercy; the pacificist or the pro-German is not going to have blood sprinkled over his lintel, as it were, to exempt him from the penalties of the defeat of this country.

The Chairman.—I shall now ask a gentleman to speak to us who was not only early in the business and naturally went to the front in Washington, but has been able to make all the rest of us work for him.

W. Y. Westervelt.—As you know, the members of the War Minerals Committee are not full fledged bureau people; we are a voluntary committee of the two great bureaus in the Department of the Interior, the Geological Survey and the Bureau of Mines, and of the mining engineers and geologists of the country, as represented by this Institute, the Mining and Metallurgical Society and the Association of State Geologists.

The War Minerals Committee has been working since early last summer trying to organize a constructive attitude in Washington to oppose all the multifarious destructive attitudes which would naturally prevail. The Army and Navy, rightly, are supreme in Washington today. If we have all got to shoulder muskets at the command of the Army and the Navy, we are all going to do it; we do not hesitate a minute about that. But, gentlemen, as President Wilson stated last April, it needs now not merely an army and a navy, but it takes an entire organized nation to go to war. This organized nation must have a constructive policy; it must think not only of this year, but of next year and the one after and of how many more years. With a victorious Germany as she stands today, have we any thought of ending the war this year? It would be insane not to prepare for years, and we don't dare say how many years.

How can we meet this situation from an industrial standpoint, and how did the War Minerals Committee come to have anything to do with it at all? One of the first things we encountered was the necessity for stimulating domestic production of pyrites and manganese. Both the Survey and the Bureau of Mines had already begun to gather statistics on this subject, and when they placed their results before us it quickly became evident that something had to be done. That was in July; what has been done?

As to pyrites, there has been some stimulation, and a little stimulation of manganese, but nothing to what we are obliged to have. Spanish pyrites, on which the country depended, have continued to be imported spasmodically whenever you gave a tremendous roar to the Shipping Board, that if you did not get some pyrites right away, acid

plants would shut down and munitions manufacture would cease. But the shipping board is realizing more and more that, no matter what happens, freight ships will have to be withdrawn from all sources. You cannot get the pyrites developed so long as the ships are running; and you cannot stop the ships until you develop domestic manganese; and you cannot use domestic manganese until there is a modification of the steel practice; and you cannot modify the steel practice so long as there is plenty of manganese ore in sight; and there will be plenty so long as you use 20 or 30 large-tonnage ships to bring it from Brazil, ships that ought to be going across the Atlantic.

We finally came to the conclusion, last December, that the gathering of statistics would have to stop, and that power would have to be asked for definite action. We began to look around to see what powers could be secured, and we thought of Mr. Hoover. He said, "You are striking right at the fundamentals of the administration of this war. In the first place, there are no such powers; you have got to go to Congress for that legislation." We explained that we wanted an administrator for pyrites and manganese, and were beginning to wonder if there were not some other things, such as chromite, that needed fostering from the Government. He said, "Don't stop to think about an administrator for each one of those; go in for the whole mineral and chemical industry of this country." We looked at him in blank amazement. "What is this you are suggesting; an industrial President of the United States?" He said, "If you don't make some such arrangement in the next three months you will see industries beginning to be tied up, and showing the same signs of confusion we are beginning to see in the railroads. Wait and see what is going to happen to the railroads in the middle of this winter." This was in early December.

Things began to look pretty serious, and we wondered whether our committee, representing only a particular section of industry, could undertake so large a program. We looked around and found that nobody else was doing anything; so, after advice from Mr. Manning, Mr. Moore, Mr. Baruch, Mr. Willard, Mr. Requa, and Mr. Rickard, we decided to draft a bill and take it up to the Mines Committees of the House and Senate.

You will see in the February issue of the *Bulletin* a copy of the bill as we drew it up. This bill was to have been introduced in Congress the very day on which the Fuel Administration announced our heatless days; needless to say, that was not an opportune time to propose to increase the powers of the administration.

More recently, however, influential Congressmen have told us, "We will introduce this bill, which we think ought to be introduced, but we feel that you ought to leave out such little industries as steel and iron, and lead, and copper, and zinc." We agreed to this, but insisted on the regulation of pyrites, manganese, chromite, and other minor minerals, for which we know that regulation is essential. Many of our friends have taken issue with us about that. They say, "Don't compromise; let this confusion go on until it becomes so perfectly frightful that there will be a grand rush for cover." I am afraid of that method; let us have a part measure, if we cannot have a whole one. Let us try the plan on a smaller scale, and if it works, then the other and bigger industries are going to seek cover.

None of us, as engineers, likes governmental interference; we were not

brought up under a bureaucratic system and do not understand it. I have never had anything to do with government work, have never known anything about it, but I have come to realize, from my little experience in Washington, that in these days things have got to be done by governmental authority; the method of indirection through which so much of the work has been forced has simply got to stop. We have reached the time when powers must be properly designated and definitely defined. I ask that when you examine the general features of this bill and criticize it and object to it, you stop to consider it from two aspects; first, we have got to win this war, of course, and must coöperate in every way we can; second, might it not be to the interest of your own particular industry, to be protected against the present confusion and disorganization.

I ask if you will not, each of you, study the bill; think of its relationship to your own industry, if it affects it at all; think of it from the standpoint of what will be shortly coming, when we have two million men in France. Won't you try to help us toward a constructive attitude in Washington, and to get the power whereby constructive action can be taken?

ANNUAL MEETING OF THE WOMAN'S AUXILIARY

The annual meeting of the Woman's Auxiliary was held on February 19, at 10 a. m. The president, Mrs. Sidney Jennings, said in her greeting "it is a matter of congratulation that during the past year when the demands upon women for work of all kinds has been so large our membership has grown from the 50 enrolled at the first meeting a year ago, to over 300 today.

Some women, when asked to join the organization, say that they are doing so much work in other ways that they have no time for work in a new organization, but the director for Canada struck the right note in her report when she told us of the splendid work the wives of mining engineers are doing in Canada, as individuals and as leaders and members of various organizations doing patriotic work. We do not want to divert such women from the work they are now doing, but we do want them to enroll as members of the Woman's Auxiliary and let us know what they are doing, that they may give inspiration to others."

Reports were made by the directors of the following sections: Canada, Chicago, Colorado, Columbia, New York, Puget Sound and St. Louis, in some of which sections excellent progress has been made in food conservation, foreign war relief, including the adoption of fatherless French children, and in work for our own engineering regiments. These reports were read, accepted, and placed on file.

The reports of the corresponding secretary, of the recording secretary, and of the treasurer, were read, accepted, and placed on file.

Various amendments to the Constitution were proposed and accepted, and copies of the Constitution, as amended, will be mailed to all the members of the Woman's Auxiliary.

The election of officers of the Central Council for the ensuing year resulted as follows:

President,	Mrs. Robert C. Gemmell, Salt Lake City.
Vice-President,	Mrs. Louis D. Huntoon, New York.
Second Vice-President,	Mrs. Karl Eilers, New York.
Third Vice-President,	Mrs. Levi P. Holbrook, New York.
Secretary,	Mrs. Sidney J. Jennings, New York.
Treasurer,	Mrs. Harris K. Masters, New York.

On Tuesday afternoon, some exceedingly interesting moving pictures, showing the work of the Civilian Committee of the American Fund for French Wounded in the devastated regions of France, were exhibited by Mrs. Needham, herself one of that Committee; a large and interested audience attended the lecture. As will be seen below, the Central Committee on Foreign War Relief recommends some special work to be done in this region.

On Wednesday morning, Dr. Kellogg, who was originally associated with Mr. Hoover in his relief work in Belgium, and who is now engaged in food conservation, addressed an interested audience, showing very clearly that if we are to win the war we are waging for liberty, the women of America must do their part, and that a large and active one, in the conservation of food, and the substitution of other *cereals* for wheat, so that we may feed, not only our own men, but those of our allies, who for the past three years have been unable to produce the food necessary for their sustenance. The ladies present took notes of Dr. Kellogg's lecture, asked questions about wheat substitutes, and promised to conform to the Food Administrator's recommendations.

These were the chief activities of the annual meeting, but the members shared in all the entertainments planned for our visiting members by the New York Entertainment Committee. These included visits to the magnificent art galleries of Mr. Frick and Senator Clarke, who once again most generously threw open their doors to the members of the Institute and their families; a visit to the Metropolitan Museum of Art; a matinee of Chu Chin Chow at the Century Theater; a reception at the home of the newly elected President, and Mrs. Sidney J. Jennings; the annual banquet (this year a Hoover dinner); and a most delightful visit to Princeton University, and the Ground Aviation School.

We hope that next spring there may be better travelling facilities, and that all our members may be able to attend the annual meeting.

The Committees on Americanization, Emergency, War Relief, and Foreign War Relief give their reports and recommendations below; it is hoped that every member of the W. A. I. M. E. may be able to find some work which she can carry on or organize in her immediate vicinity.

Recommendations of the Americanization Committee

We believe the best way to reach the parents of our foreign population is through their children, and they should be taught how to salute our flag and reverence it, see that it is taken down at sunset, see that a flag is placed at every school and town hall. Teach the children the history of the flag, what the stripes mean, what the stars mean, and the history of the United States in condensed form, including our reason for celebrating July 4, February 22, and April 19, etc.; also teach them what naturalization papers are, and how to procure them.

A very important present duty is to teach the women how to vote, in those states where they are permitted to do so.

Many foreign women have been brought up with very little knowledge

of cooking. Teach them the use of the most wholesome foods, how to get the best out of a small piece of meat, for working people must be well nourished to keep the muscles in good condition to do manual labor. Have sewing classes to teach the women how to cut out garments and how to sew them. Often these classes will open the way for a desire for citizenship among aliens.

One of the first steps in Americanization must be a school where the adults can learn to read and speak English. There might also be clubs where they can be entertained.

MRS. LEVI P. HOLBROOK, *Chairman.*

Report of the Central Emergency Committee

During the past year, the Emergency Committee has done good work in the New York Section. On the Committee were Mrs. H. A. Prosser, Mrs. A. Dwight, Mrs. J. F. Kemp, Mrs. Weinberg, Mrs. Raymond, Mrs. Karl Eilers, Mrs. H. W. Hardinge, Mrs. Louis D. Huntoon and Mrs. Morse.

Early in the year some of the members were actively engaged in canteen work, and later on they took up work for the 11th Engineers, with whom they kept in touch through Major and Mrs. A. S. Dwight, who were in France. The sum of $306 was sent to Mrs. Dwight to expend for the regiment in any way she thought fit, and later on a sum of $141 was sent to Major Dwight to be used for the men at his discretion. Later on a check for $100 was sent to the treasurer of the 11th Regiment Association. Before Christmas the ladies set to work, and with an expenditure of $500 made comfort kits and Christmas gifts for the men of the 11th "over there." Tobacco, candy, chewing gum, toilet requisites, etc., all went into the boxes and bags which were filled and dispatched by the Committee. A total of $1047 was collected and disbursed for our engineers "over there" by the New York Section alone.

At the time of the Halifax disaster, the Committee at once dispatched a quantity of clothing and a check for $288 to the Rev. Dr. Lemoine, to be used for the poor and destitute in his parish, which had suffered terribly in the explosion.

Individual members have practised food conservation during the summer, carrying out the recommendations of the food administrator to bottle and preserve as much garden stuff as possible.

MRS. H. A. PROSSER, *Chairman.*

Recommendations of the Central Emergency Committee

The Emergency Committee recommends that for the ensuing year, efforts be made toward the conservation of food—that potatoes and other vegetables and fruits should be grown where possible, and centers established for bottling and canning. Where this cannot be done, no doubt individuals will do much in their own kitchens to preserve the fruit and vegetables they grow.

They also recommend the work for the 27th Engineers, a special mining regiment, which is being recruited with miners and mining engineers from all parts of the country. They are our own men, belong to our own profession; let us keep them going. Knitted socks are needed for them all the time—the life of a pair of socks at the front is about five days—keep knitting. Money is needed for the purchase of tobacco,

cigarettes and athletic equipment, etc., and there may be need to give help in emergencies to those left behind. Contributions small or large will be gratefully received. In order that all donations may be credited to the proper section of the W. A. A. I. M. E., please send them through your chairman or director to Mrs. H. N. Spicer, Chairman Central Emergency Committee, Woman's Auxiliary of the A. I. M. E., 29 West 39th Street, New York City. All knitting should be sent by parcel post and insured.

Report of the Central War Relief Committee

On June 1, 1917, the United States Government took over the "necessary contributions" for Belgian relief, and the director of the Commission for relief in Belgium notified the various committees formed for the purpose of aiding that work that no further appeal for money would be made for the present, but advising that the organizations should be kept alive as their services might be required in the future. If the Commission makes the demand for clothing which is contemplated, we shall again turn to the work for Belgium, which lies so near our hearts.

On Feb. 2, 1918, the Belgian Relief Committee was re-formed for the purpose of foreign war relief, and it was decided to work through the Civilian Committee of the American Fund for French Wounded, whose activities lie in the devastated regions of Northern France. This is also working in coöperation with the Red Cross.

The people who are being brought back to the districts lately occupied by the enemy need everything, food, a roof to cover them, clothes, furniture, farming implements, and artisan's tools, and it must be borne in mind that the able-bodied men and women have been deported. Among such a multitude of needs it is difficult to choose which to endeavor to supply, but as the large area of uncultivated land offers pasturage to sheep and cattle, the special work we have undertaken is to raise money for a flock of sheep; one person can care for a number of sheep, and this is an important consideration, in view of the shortage of labor.

In aiding in any way to bring the peasant back to the land, we are furthering the purpose of the French Government, and engaging in constructive work, thereby supplementing the task of our engineers in France.

Since August, nearly four years ago, when Belgium and France met the full brunt of the onslaught on civilization, France has been expending her utmost in blood and treasure and energy, and all that her people could put forth, and now the time has come when she must have help, and we must give it not alone from our abundance, but from our sacrifices. Until the day comes when we too can say "we are giving our all" we shall not be doing our part.

Sophie C. Knox, *Chairman.*

Recommendation of the Central Foreign War Relief Committee

The Committee for Foreign War Relief, of the New York Section, has decided to undertake as its first effort the task of raising money to supply sheep for the Aisne region, since sheep-raising is the most effective use to which the land can be put until such time as it can be restored to cultivation.

Sheep can be provided at $15 a head and one person can care for a number, a serious consideration in view of the dearth of able-bodied

men and women in the districts lately occupied by the enemy. Among our Allies who have suffered the most in the three and a half years of warfare, France makes the most direct appeal to us because we can get supplies to her, and the French peasant in the recovered territory must be furnished with the essentials of his calling before he can again become self-supporting.

The Committee asks that your contribution toward this object be as generous as possible and that you strive to interest others in our common endeavor.

In order that your contributions may be credited to your own Section of the W. A. A. I. M. E., please send them through your director or chairman to Mrs. H. H. Knox, Chairman Central War Relief Committee, Woman's Auxiliary of the A. I. M. E., 29 West 39th Street, New York City.

REPORTS FOR THE YEAR 1917

PRESIDENT P. N. MOORE

Delivered at the Annual Meeting, New York, Feb. 19, 1918

Your outgoing President, following the worthy example of distinguished predecessors, submits a reckoning of his stewardship. He renders this fully realizing that without the hearty coöperation of Directors and Secretary, which he here recognizes most cordially, no President, who at best is but a passing force, can achieve markworthy results.

The details as to your membership, finances, intellectual output, and other activities, have been submitted in the report of the Secretary. It is enough to emphasize that during the year just expired, your organization has held two of its most successful meetings—one the largest in its history—has produced the largest number of papers, eliciting most interested discussions, has enjoyed its greatest income, and has received more than one thousand new members—passing the best previous record by more than one hundred, and exceeding the average increment of the past five years by one third. It closes the year with 6528 members, the largest enrollment in its history.

All of this might be true and yet the intellectual and social spirit, the loyalty of membership, the real life of the organization, *might* remain stagnant. As to these, it is for others than your speaker to testify. No comparison is feared.

Stimulation of Local Sections

One year ago, assuming the duties and accepting the honor bestowed by you, your speaker stated his belief that encouragement of the activities of local sections offered the most promising means of holding the interest of your members and improving the *esprit de corps* of the main body. At the time, he promised as his share, if possible, to visit every section. Within the year he has foregathered with all but two; the failures came through no fault of his, but through infrequency of their assemblings. In such visits and on other business of the Institute,

including necessary journeys to attend monthly Directors' meetings, and to Washington, he has travelled some 30,000 miles.

The response which has come from these contacts has been most encouraging. Your speaker believes fully that they have influenced the growth of interest and the solidarity of the organization. In past years it has often been said that the Institute is finding itself. May your speaker repeat this: the organization is always finding itself anew and anew. Never before, in his belief, has interest been more widely extended, the technical stimulus greater, or membership counted for more than today.

One would prove a dull student of history were he to claim for his contemporaries greater intellectual capacity or literary appreciation than was possessed by the leaders who founded this Institute and led it through its adolescent years. On the contrary, it is doubtful whether the active ranks of the present day includes the equals of some of those masters in the days gone by. Further, their concept of the real functions of the Institute was keen and farsighted. They saw the same problems and dangers, and the same solutions as do we.

It has been a great pleasure, looking backward over your records, to come upon the recommendations of your President of thirty years ago—a friend of many years, William B. Potter— in that day a man distinguished and admired. In his presidential address, his vision saw our problems much as we see them now. His recommendations were for the establishment of sections, substantially the same as the idea which was carried out by another brilliant mind, Mr. Charles F. Rand, our President twenty-five years later.

Such a body as the Institute has ever before it the two extremes of policy, either one of which, followed too far, leads to disaster. One is centralization with efficiency; the other, wide control with a large number sharing in its problems, mingling in its affairs, and thereby possibly leading to confusion, if not disharmony; and yet, both policies are needed.

An effective body must have its centralized working board easily assembled, and able to speak with authority; at the same time, if its widely distributed membership, doing the real work of the profession in the mountains, mills, and smelters, be not consulted actually, instead of nominally, if these men be not made to realize that they count, that their judgment is desired and has weight, inevitably loyalty lapses and yields place to indifference and criticism.

The problem of wider or more democratic participation in the affairs of all national engineering societies is one of great difficulty, because, from the nature of things, the majority, especially of the men in their subaltern days, inevitably dwell in isolated communities, where opportunities for personal contacts with their equals, who think along the same lines, are rare. These are the men who are doing the real work of the profession. Those who dwell in the great cities have either passed subaltern days and reached the dignity of being no longer in the service of any one employer; or they are the chiefs of the great technical organizations needed at the nerve centers of the country for frequency of counsel and efficiency of control.

The time removed from field contacts is apt to measure a certain loss of sympathy with the point of view of the field man. By such detachment he loses the insight of the younger man and tends to consider our common

problems from the viewpoint of his neighbor. This is unconsciously done, and absolutely without intent to be inconsiderate. Its improvement constitutes one of the difficult problems of society administration; and yet, without its constant consideration in plan and action, the society loses the warm loyalty of the younger man which is its best asset for the future.

In the local section the younger men have opportunity to meet their elders, to bring to preferment those whom they esteem, and through them, as representatives, to make an impression upon the consciousness of the main organization. Probably never before have your national officers so fully realized this situation, or so sincerely desired to give it cordial consideration.

Your speaker dwells on this, that our members far removed, who may for years have no opportunity to attend the Institute's meetings, may yet realize that they are valued and considered. Further, may he bear in upon them that the Directors desire to know their wishes, and that letters of suggestion or criticism are always welcome and will receive interested attention. Your Directors are busy men of great affairs, who take from their crowded hours valuable time to give detailed attention to your problems. The good of the profession and of the Institute is their object. They are always glad to know the judgment of men who, from their viewpoint, may necessarily see things differently.

In your speaker's opinion, the local sections afford the best means to meet this situation; bringing the distant members into articulation with the main society, so that they are made to feel that membership brings obligation as well as satisfaction, and that they must share the reproach if its conduct shall not be for the best interests of the profession. He believes fully that this spirit is working among them and that, as never before, have they taken a more active interest in the affairs of the Institute. Individual problems of each are for them alone to solve, but an annual visit from the President, some other officer of the Institute, or from some prominent member who may happen in their neighborhood, will be of great service, by keeping them in touch with affairs and by rendering counsel from experience of the methods by which similar problems are solved elsewhere. With such increased activity of the local sections there need never be occasion for the criticism by any member that the wishes and judgment of those far from headquarters receive little consideration.

This conclusion, the wages of experience, brings a recommendation which your speaker may now voice for the benefit of his successors. No longer interested in the results which may follow, and able to speak disinterestedly, he recommends that a travel allowance be made to cover expenses of your President, to enable him more fairly, as well as perhaps more freely, to make it one of his duties to visit each section of the Institute during his year of presidential honor and service.

This great organization, with membership all over the world, cannot be expected to bring to its members the intimate personal friendships which the smaller, more homogenous body might secure. The local sections, however, offer a means of correcting this deficiency, of bringing men together in somewhat homogenous units and giving them the friendly touch of elbow to elbow around the council or banquet table, which brings great dividends of friendship.

Patriotic Work

Coming to your leadership at a time of great national anxiety, your speaker was hardly installed ere this country joined in the world war. The question at once rose: What can the Institute do of national service? Following pilgrimages to Washington, certain conclusions forced themselves upon him. One was an impression of great confusion and duplication of work by officials and departments, as well as by patriotic volunteers, arising through lack of organization, and for which reason it would be unwise to attempt immediate independent service by the organization, as such. By elimination also, it was clear that nothing should be undertaken in duplication of work already in the hands of others, no matter if it might seem that such work could be more fitly assigned to our members; and, second, that whatever be undertaken, it should be through the official bureaus of the Government already dealing with matters wherein our profession is expert.

Questionnaire.—One of the first efforts toward acquiring systematic knowledge of the personnel of the profession came in a questionnaire over the signatures of Director Manning, of the U. S. Bureau of Mines, and your President, addressed to the members of our profession throughout the United States. This questionnaire called for information in great detail as to the experience, qualifications, and desires of the men questioned. The answers were very satisfactory and as the outcome, a list of some 7500 mining engineers of the United States is now in the files of the Bureau of Mines, and the Institute, which gives a more complete record of the profession than ever before achieved. It is fair to state that practically the whole burden of this work was carried by the U. S. Bureau of Mines.

War Minerals Committee.—This organization was largely the outcome of the efforts of Mr. W. O. Hotchkiss, Secretary of the Association of State Geologists. It consisted of four representatives, one each from the U. S. Bureau of Mines, U. S. Geological Survey, Association of State Geologists, and the American Institute of Mining Engineers.

It was your President's privilege to name as representative Mr. Wm. Young Westervelt, whose fitness was promptly recognized by the Committee by selecting him as its Chairman. This Committee, having already at command in the files of the U. S. Geological Survey and the Bureau of Mines, the largest stores of information about minerals most acutely needed by the country in the present crisis, has, in the months since, devoted itself to the gathering of additional facts, at the same time giving information and advice to intending developers. It has been and is rendering valuable service to the country. Its work has led to recommendations of constructive policy, which no other body was in so favorable position to make. These cannot be published in full here, but their suggestions have been received with respect and welcome by the powerful committees in Washington, and will count in impending decisions of great importance.

From time to time your speaker has been asked to name committees from the membership of the Institute for particular tasks of investigation for the information of some of the great supply departments of the Government. One of these was for the study of manganese problems in Virginia; another for investigation of the sulphur situation in Texas and Louisiana, and still another, now in action, of expert steel metal-

lurgists to investigate and advise on the use of manganese alloys in our steel industries with a view to increased consumption of spiegel instead of ferro-manganese during the war, thereby releasing vessels now engaged in the importation of high-grade manganese ores for service more needed elsewhere.

Your speaker desires to express his appreciation of the cordial way in which the U. S. Bureau of Mines and the Geological Survey have honored us by calling for our services; at the same time he recognizes the patriotic spirit with which so many of our distinguished members have put themselves at the service of the country without remuneration.

Engineering Council.—As an instrument to voice the future policy of the profession at large, and at the request of the officers of the United Engineering Society, representing the four great founder societies who occupy this building, the Engineering Council has been formed, composed of five members of each of these constituent societies, with five from the United Engineering Society, which in its turn is a representative body, so that the Council is in essence representative of these four societies. It is the hope of its founders that the Engineering Council shall represent not alone the engineering profession in all matters of public or national interest, but eventually the other great technical national societies. To this end the articles provide a means by which such other bodies may be admitted to representation.

In the judgment of your speaker, this Council represents the best tool yet forged wherewith the profession may serve the country. As yet, it has not found opportunity to justify the hopes of its originators. This is partly through lack of initial financial support from the constituent societies, but after some months a start has been made, and an able Secretary has been secured. It is the hope of its friends that this Council shall take over all public questions which are not interdicted by some one of the founder societies, and become an efficient means by which the judgment of the engineering profession can be impressed upon the public consciousness. Its problems are many. Undoubtedly some enthusiastic men will feel that it lacks sympathy with their particular propaganda, but in the end, your speaker looks on the Engineering Council with hope. He commends it to your heartiest support, moral and financial.

In this connection it is well to enforce upon the attention of our membership that increasing the activity inevitably brings corresponding expense and therefore demands greater income. With our present organization, income is closely balanced by outgo. The growth in membership which we are witnessing brings with it corresponding cost. The necessary cost to the Institute per member is greater than the receipts from him, and it is only incidental receipts from sale of publications and from advertising which enable us to to close the year with a small surplus. In the year just closed the outgo has exceeded receipts of all kinds from members (including initiation fees), approximately eleven thousand dollars.

If the engineering profession is ever to claim its rightful place in the public eye and esteem, the organizations representing it must be more liberally financed than in the past. At present, the Engineering Council and its committees alone need, and could wisely spend, many thousands of dollars in professional and patriotic work, thereby rendering great dividends in service to the country and repute to the profession.

The public in the past has been given to considering the engineer as

a technical man, an instrument or tool only, the plans back of which are formed in brains of another type of training. The record of the present time is doing much to enlighten the public as to the error of this view. Much more can be done patriotically, and for the good of our profession, if these joint committees of the great societies can be liberally sustained and given means wherewith they can work.

War Committee of Technical Societies.—One of the early branches of the Engineering Council, formed at the instigation of one of your members, Mr. E. B. Kirby, who saw the great unutilized store of inventive ability in the members of the technical societies of the United States, is known as the War Committee of the Technical Societies of the Engineering Council. This Committee, by consent of the Engineering Council, added representatives from others of the technical societies of the country and now represents a membership of 36,000 scientific men.

It too has been cramped in its activities for lack of means, but through collaboration with the Naval Consulting Board, it has been able, under the chairmanship of D. W. Brunton, to organize, and is doing valuable work. It is your speaker's advice that all possible support be given to the Engineering Council that in turn the work of this Committee be not allowed to languish.

Members in Military Service.—In common with our other societies, your Institute is sending its representatives to the front—our growing honor roll now numbering nearly six hundred men, who have put themselves at their country's service.

Publications

Your publications have attained a number and bulk which make them a grave problem to your Finance Committee, as well as to your editor. It is a question whether the membership will desire to receive more than three volumes each year, or whether the treasury will permit. It will, therefore, doubtless soon become necessary still more rigidly to eliminate less important papers, leaving their publication and preservation for the Bulletin alone. This, in turn, will bring more work for the Publication Committee.

The Bulletin has been one of the interesting problems, although, naturally, it is felt more heavily by your Secretary than any one else. His desire is to make it so interesting to the membership that it shall be looked for, opened, and read with as keen an interest as the daily newspaper or the weekly technical journal. Its advertising, now in new hands, is showing a growth justifying the change in policy, and it is hoped by this means to secure returns sufficient in turn to apply more and abler editorial talent to the preparation of the Bulletin.

Library

Your Library, now a part of the joint library of the United Engineering Societies, has witnessed a great addition in the library of the American Society of Civil Engineers during the past year. We can now say without challenge that the joint library offers to the members of the founder societies access to the most complete body of engineering data existing. It is greatly desired that our members shall use it freely by mail, calling for searches and reproductions on subjects which they are investigating. Such service is increasing, but we wish our members to know that it is willingly at their command.

Consolidation of Technical Societies

The vision dwells in the minds of many that ultimately these four great societies, lightening the emphasis they place upon their differences, may see the time when, for the solidarity of the profession, for their best interests, as well as for increase of their influence on the country at large, they may become one great national association of engineers. With the gain in power and prestige inevitably following such an aggregation, freedom for individual development may be achieved through divisions along the lines of technical interests, which might either follow the present four grand divisions, or be more minutely subdivided.

An organization of this sort could and probably would be more strictly professional than any of the four have been heretofore, and through the prestige and power of its numbers could establish standards of ethical conduct for its members, violation of which would bring grave consequence.

Our own organization has so far never declared an ethical code, but your speaker firmly believes demand for one will surely arise. The phases of our activities are so variant that to frame such a code in detail will be difficult, but the broad principles of ethics will always apply when based upon the postulate that no engineer can ever bear a concealed relationship to any enterprise wherewith he is directly or indirectly connected. There is no reason why an engineer should not profit by developments which are the result of his own skill. In fact, the engineer who confines himself to purely salaried or unparticipating relations toward any enterprise can never secure the full share which his brain and aggressiveness may bring it, but it is of vital importance that any interest which he may have shall be fully disclosed.

Amendment to the Constitution

Following the example of our sister societies, a wide demand from our younger members, and acting upon a petition signed by them from all over the country, an amendment to our Constitution, proposing a change in standards for membership which will make the organization more strictly technical and professional than in the past, has been submitted for your decision. Our young technical men possibly value their diplomas and their training at a higher rate than some elders who appreciate that often the man educated in the "University of Hard Knocks" outclasses the younger whose training was in institutional halls in his youth, but the change is in line with the trend of things, and it is believed by its proponents will bring greater respect for the Institute, and largely increase its membership. It is in line with the policies of our affiliated societies, with which we hope our contacts may grow closer.

Your speaker learns with satisfaction that the amendment has been adopted by a vote in which ninety-five per cent. of those voting favored the measure.

In closing, your speaker thanks you for the honor given him, for the opportunity for service, for the friendships and acquaintances the year has brought. Each new contact with the Sections of the Institute has brought him a clearer realization of their value to its members, and an increasing pride and respect for them.

THE SECRETARY

The year 1917 has been a notable one in Institute affairs. The usual activities, including meetings, publications, local section interests, library service, and so forth, have been continued on at least the same scale as previously, and in addition the resources of the Institute have been placed without stint at the service of the Nation, not only for the active prosecution of the military side of the war, but even more especially in the industrial operations which form the very basis of modern warfare. The officers and directors of the Institute have labored both officially and individually, while the Institute as a body, through committees of prominent members, and through many individual members, has given freely. Finally, Institute funds have been appropriated to an amount exceeding $5000 to accomplish the coöperation with Government bureaus, and provide committee expenses necessary for performing the services that have been given. The President of the Institute had a very large personal share in many of these activities, which will be described in the following pages, as well as in the President's own report. Many of the Institute's members are giving their whole time for $1 a year, or less, and especial mention should be made of Herbert C. Hoover, Food Administrator, W. L. Honnold, Head of the Commission for Relief in Belgium, Mark L. Requa, Petroleum Administrator, Edgar Rickard and Charles W. Merrill of the Food Administration, S. A. Taylor of the Fuel Administration, W. L. Saunders, B. B. Thayer and Joseph W. Richards who are giving a large share of their time to the Naval Consulting Board, W. Y. Westervelt, W. O. Hotchkiss and Harvey S. Mudd of the War Minerals Committee, David W. Brunton of the War Committee of Technical Societies, and hundreds of others whose names are mentioned in the Honor Roll of Members. It has also been a notable year in coöperation with sister societies. The most important event under this head was the accession of the American Society of Civil Engineers into the fraternity of Founder Societies.

Visits by the President to Local Sections.—President P. N. Moore made a distinct advance in Institute policy byavisiting many of the local sections of the Institute, more particularly the sections most distant from Headquarters. Accompanied by the Secretary, he traveled to Reno, Nev., where he was entertained at a special meeting of the Nevada Section on May 3. Members were present from many different parts of the State of Nevada. Addresses were made by the President and the Secretary, and a general discussion on Institute policies was held, in which almost everyone present took part. In the evening a dinner was tendered to the visitors and the next morning the President and Secretary addressed the engineering students of the University of Nevada, meeting later with the student society affiliated with the Institute.[1]

The officers next attended the annual meeting of the Southern California Section in Los Angeles on May 5. Institute policies and activities were again the subject of discussion, the meeting beginning with a dinner and extending well into the evening.[2]

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[1] See Bulletin for July, 1917, p. xlv.

[2] See Bulletin for September, 1917, p. xxxii.

On May 7, a dinner and meeting of the San Francisco Section was held in San Francisco.[3]

On May 9 and 10, the President and Secretary were entertained by the Puget Sound Section, at Seattle, Wash. The entertainment in this case included an automobile trip about the scenic highways of the city, followed by visits to the leading industrial plants in the city and neighborhood, with a luncheon, and finally a dinner was given in honor of the visitors at the Arctic Club. At this dinner addresses were made by the President of the Seattle Chamber of Commerce and Commercial Club; the Pastor of the First Presbyterian Church of Seattle; the General Manager of the Fisher Flour Mills, and other captains of industry, representing coal, lumber and mines, also by the local representative of the U. S. Bureau of Mines, as well as by the President and Secretary of the Institute.[4]

The President then went to Spokane, Wash., where he was cordially entertained by the Columbia Section, after which he proceeded in company with many members of the Section to the International Mining Convention, held in Nelson, B. C., May 17–19. A full account of this most inspiring meeting, believed to be the first official meeting of Canadian and American mining engineers since the declaration of war, is contained in the Bulletin for July, pages xxxv to xxxix, inclusive. About 500 delegates attended.

On May 17, Spokane, the Columbia Section passed the following preambles and resolution:

WHEREAS, on May 5, 1915, the members of Columbia Section, A. I. M. E., were honored and greatly benefited by a visit from Secretary Stoughton and Professor Joseph W. Richards, and

WHEREAS, on May 17, 1917, they were again privileged to honor as guests President Philip N. Moore and Vice-President Charles W. Goodale, and

WHEREAS, all members of this Section are agreed that personal contact with high officials of the Institute makes for a better understanding of the plans and procedure of the Board of Directors and the great work of the Institute as a whole, thereby binding the West more closely to the East, now, therefore, be it

RESOLVED that Columbia Section, A. I. M. E., unanimously urges the Board of Directors to encourage such visits in future, particularly to those Sections lying farthest from New York, and to endeavor to find a measure of making them annual events at the expense of the Institute. And be it further

RESOLVED that this resolution be spread upon the minutes of the Section and that a copy thereof be submitted to the Board of Directors.

At Butte, Mont., on May 21, 1917, the President was entertained by the Montana Section, the entertainment consisting of visits to features of interest in the mining district and a dinner and reception. Vice-President Charles W. Goodale then accompanied the President to a meeting of the Utah Section, held at Salt Lake City on May 24, and attended by over 100 members and guests. The dinner was preceded by an entertainment of the President and Vice-President during the day and by a visit to the Utah Copper Company's mines at Bingham.[5]

The final meeting of the President's trip was held at Denver, Colo., and consisted of a dinner and reception by the Colorado Section. Besides President Moore, T. A. Rickard was also a guest on this occasion, and addresses were made by these gentlemen as well as by George M. Taylor and Thomas B. Stearns.[6]

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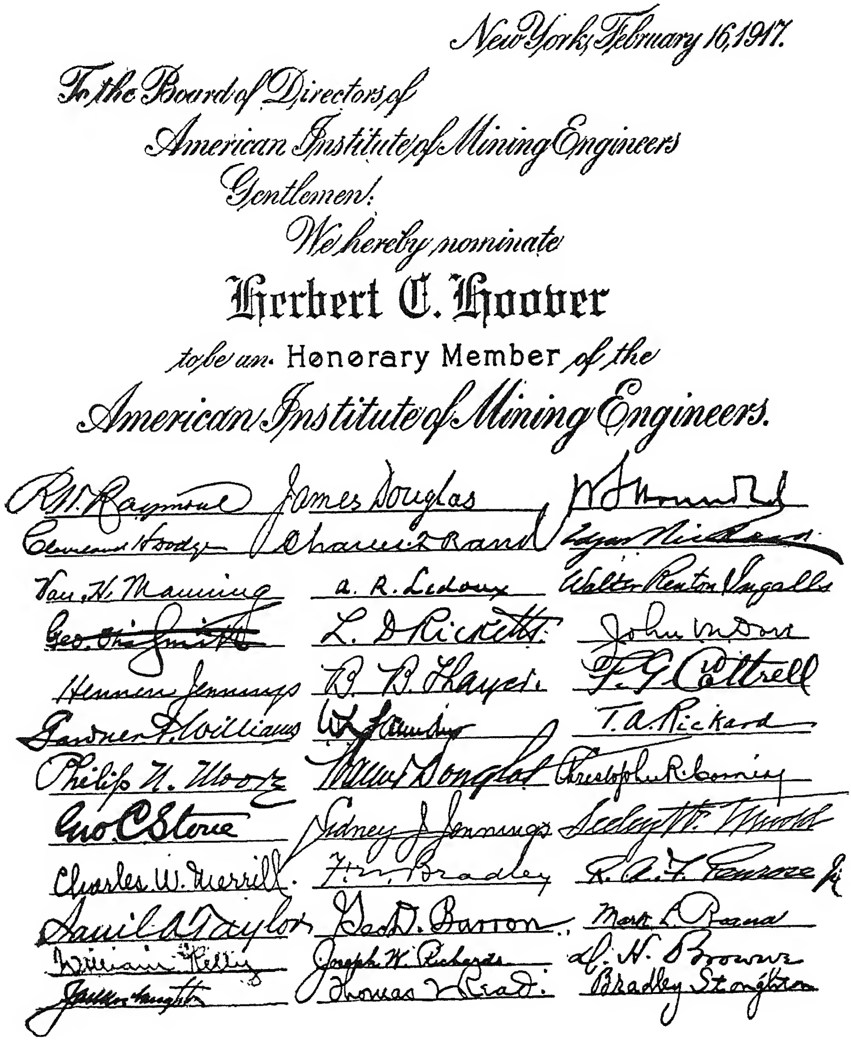
[3] See Bulletin for October, 1917, p. xxxiv.
[4] See Bulletin for July, 1917, p. xlvi.
[5] See Bulletin for August, 1917, p. xxi.
[6] See Bulletin for July, 1917, p. xlv.

On September 27, 1917, the President was the guest of the New York Section, and on November 24 the President and Secretary were entertained by the Pennsylvania Anthracite Section. The entertainment consisted first of a delightful luncheon at the home of Vice-Chairman Edwin Ludlow, preceded and followed by a trip of about 30 miles through the Pennsylvania anthracite district, and concluding with a dinner and meeting of the Section in Wilkes-Barre.

Honorary Member.—On Feb. 20, 1917, the Board of Directors elected Herbert C. Hoover an Honorary Member of the Institute, upon the



New York, February 16, 1917.

To the Board of Directors of
American Institute of Mining Engineers
Gentlemen:
We hereby nominate
Herbert C. Hoover
to be an Honorary Member of the
American Institute of Mining Engineers.

R. W. Raymond — James Douglas — [illegible]
Cleveland H. Dodge — Charles F. Rand — Edgar Rickard
Van H. Manning — A. R. Ledoux — Walter Renton Ingalls
Geo. Otis Smith — L. D. Ricketts — John V. N. Dorr
Hennen Jennings — B. B. Thayer — F. G. Cottrell
Gardner F. Williams — W. L. Saunders — T. A. Rickard
Philip N. Moore — Walter Douglas — Christopher R. Corning
Geo. C. Stone — Sidney J. Jennings — Seeley W. Mudd
Charles W. Merrill — F. W. Bradley — R. A. F. Penrose Jr.
Samuel A. Taylor — Geo. D. Barron — Mark L. Requa
William Kelly — Joseph W. Richards — H. N. Browne
[illegible] — Thomas T. Read — Bradley Stoughton

nomination of more than 20 members. This nomination contains the signatures of so many men at present prominent in the mining world that it is here reproduced for the interest of the members.

John Fritz Medal.—The Institute was also honored by the election of

Henry Marion Howe, Past President, as recipient of the John Fritz Medal. The presentation ceremonies were of a different order from those ever held before and a full account is given on pages xv to xxxv of the Bulletin for July, 1917. During the year 1917, the John Fritz Medal Board of Award also published a most attractive and interesting volume containing short biographies and portraits of all the recipients of the medal. This volume is sold to members of the Founder Societies through secretaries.

Honor Roll of Members.—Some members of this Institute have been actively engaged in the war for democracy and freedom since August, 1914, and we regret to announce the loss of some who have been killed in action. An Honor Roll of the Institute has been maintained in the Bulletin, beginning with the June issue, 1917, and in addition the names are placed on an Honor Roll maintained in the Members' rooms at Institute headquarters.

The Board of Directors has also followed the custom of remitting the dues of each member actively engaged in military service, upon receipt of the request from him, or someone authorized to speak for him.

Census of Mining Engineers.—The U. S. Bureau of Mines, in coöperation with the Council of National Defense and the Institute, prepared a census of mining engineers, metallurgists and geologists. Several blanks for the purpose were sent to each member of the Institute in envelopes addressed at Institute headquarters; the returns were very encouraging, since about 7500 cards were received through about 6000 persons addressed. This census has been copied and classified and is on file both in Washington and at the headquarters of the Institute. It is a valuable source of information and record, which has been used many times by departments of the Government in prosecuting the war and in industrial work in connection with the war; it has also proved very useful at Institute headquarters.

Offer of Services to the Nation.—On Feb. 5, 1917, the President of the American Society of Civil Engineers, American Institute of Mining Engineers, American Society of Mechanical Engineers and American Institute of Electrical Engineers and the United Engineering Society joined in the following telegram to the President of the United States:

> We, the presidents of the national societies of Civil, Mining, Mechanical, and Electrical Engineers and of the United Engineering Society, with a membership of thirty thousand, cordially unite in supporting Congress and the Administration in its stand for freedom and safety on the seas, and we are confident that we represent the membership of the four societies in offering to assist toward the organization of engineers for service to our Country in case of war.

This telegram was referred by the President of the United States to the Council of National Defense, resulting in the formation of a committee of the Council, upon which the Institute was represented by the President and Secretary, and Prof. Arthur L. Walker. It has been a valuable means of bringing many engineers in relation with the Government for the timely performance of service of great value.

Reserve Corps of Engineers.—A Reserve Corps of Engineers, which was made possible through the coöperation of the Institute with other bodies and with the Government, has accepted the services of many members of the Institute whose names will be found on the Honor Roll, and was also the basis of what later became established in law as the Officers' Reserve Corps, in which a great many men of the country are already engaged.

Eleventh Engineers, U. S. A.—The 11th Engineers, U. S. A., which contained the body of men who were the first Americans to fight on French soil during a recent German attack on the Cambrai sector, was recruited by the Military Engineering Committee of New York, in which were several representatives of the Institute. Major Arthur S. Dwight materially assisted in the formation of this regiment and is attached thereto.

Liberty Bonds.—One hundred per cent. of the office employees of the Institute subscribed to the first Liberty Loan. By action of the Board of Directors, the employees were enabled to secure the bonds and pay for them on installments. The entire payments were made before the close of business of the year 1917.

War Minerals Committee.—Any account of the work done by the Institute for the Nation must begin with a statement of the activity of the War Minerals Committee, consisting of representatives of the U. S. Bureau of Mines, U. S. Geological Survey, Association of American State Geologists, and the Institute. This committee has effected a coöperation of the work of the two Government bureaus and elimination of duplication thereof, besides bringing into play the large resources of the two technical societies mentioned. The project was formed in the mind of a member of the Institute, W. O. Hotchkiss, Secretary of the Association of American State Geologists, and was carried out by him and by President P. N. Moore. All the members of this committee are also members of the Institute, and beside the official representatives of the different bodies, consisting of Messrs. David White, Alfred G. White, W. O. Hotchkiss and William Young Westervelt, Harvey S. Mudd has given his entire time voluntarily and served as assistant secretary of the committee. The committee first devoted itself to analyzing and classifying the available information regarding war minerals, more particularly pyrites, sulphur, manganese ores and ores of the ferro-alloying metals, etc. Circulars were addressed to the members of the Institute through the Bulletin and resulted in bringing out a large amount of information, which had never before been collected in one place. The committee also had four important sessions during the St. Louis meeting; it appointed a sub-committee which visited Virginia for the purpose of stimulating production of manganese ore, and another sub-committee which visited Texas to carry on certain researches for the Government. Finally, the committee drafted a bill for the appointment of a Mineral Administrator (see Bulletin No. 134). This bill has been presented before both Houses of Congress, and is now pending, having received the approval of the Chairman of the House Committee on Mines and the Vice-Chairman of the corresponding Senate committee.

Engineering Council.—By a change in the by-laws of the United Engineering Society, the four Founder Societies have established the Engineering Council in order to provide for convenient coöperation for the proper consideration of questions of general interest to engineers and the public, and to provide the means for united action upon questions of common concern to engineers. In addition to the four Founder Societies, the Council may include representatives of other national engineering or technical societies elected by the Trustees of the United Engineering Society.

War Committee.—Largely through the efforts of E. B. Kirby, there was established, under the Engineering Council, a War Committee of

technical societies. D. W. Brunton is chairman of this committee, which is coöperating actively with the Naval Consulting Board in circularizing the membership of the national engineering societies and in endeavoring to bring out the inventive ability of the engineers for the benefit of the Nation.

Bulletin Presented.—In response to requests, the Board of Directors of the Institute has authorized the presentation of the Bulletin of the Institute, which is now accordingly being sent regularly, to a department of the Fuel Administration, and of the Food Administration, and to many of the training camps.

National Service.—The general relations of the engineering societies to the Government in national service connected with the war was given on pages vii to x of the Bulletin for June, 1917. These official relations have been modified somewhat since then, and it is probable that a considerable revision of the system will be made in the near future. But, in addition to these official relations, services are performed almost daily for the Government, from the appropriation of money for carryng out the war work of the societies to the voluntary service of engineers in professionally advising the Government, without remuneration, or in making examination of mining properties, and in other ways where the societies or individuals can render special service.

Engineering Foundation.—The resources of the Engineering Foundation were promptly offered to the National Research Council upon its organization, and were appreciatively accepted. The services of the two organizations were, therefore more or less combined during the year 1917. Some account of the work is given in the Bulletin for December, 1917, pages xxxviii to xlii, inclusive. It will be noted that the work of the National Research Council has now become independent of the Engineering Foundation. On this Council, the Institute is represented by about 12 members, as outlined on page ix of the Bulletin for June, 1917.

American Society of Civil Engineers.—In the Bulletin for January, 1918, page xxv, is given a brief account of the "housewarming" given to the American Society of Civil Engineers as a welcome into the fraternity of Founder Societies and into residence in the Engineering Societies' building. The act of the American Society of Civil Engineers in thus uniting with the other societies, marking as it does a great forward step in coöperation between engineers, is an important achievement of the year.

Institution of Mining and Metallurgy.—The following cordial telegram received from the President and Secretary of the Institution of Mining and Metallurgy is gladly placed on record here in the report of the year, which would be incomplete without it.

> The Institution of Mining and Metallurgy assembled in London in annual general meeting sends fraternal greetings to the American Institute of Mining Engineers and rejoices in the new bond of friendship and unity of purpose between the two societies resulting from the great historic act of participation of the American people in the war for freedom and civilization against military autocracy and barbarity.

Belgian Relief.—While the Institute cannot, without a vote of the members, officially take an active part in any relief work, cordial moral support was given by the President and Board of Directors to the most stupendous welfare work so far attempted in the history of the world;

namely, the feeding of the inhabitants of Belgium, under the direction of our Honorary Member, Herbert C. Hoover. In the President's Western trip he brought this to the attention of the members at each meeting until the relief work was taken over by the United States Government and further contributions from individuals were not requested. About $97,500 had been collected by voluntary committees of Institute members, of which between $1000 and $2000 were the result of the President's appeal. In addition to this sum, about $12,000 was collected by the Woman's Auxiliary of the Institute. In the Bulletin for March, 1917, is given an account of Herbert C. Hoover and his work in Belgium. In the Proceedings of the 114th Meeting, the eloquent address of Dr. R. W. Raymond, Secretary-Emeritus (April, 1917, Bulletin, pages ix to xi) contains a further tribute to Hoover.

Naval Consulting Board.—The very important services performed by the Naval Consulting Board are necessarily of a confidential nature that cannot be outlined in any published report. The work of the Board is now carried on on a very large scale, and in this Bulletin (February, 1918) will be found some appreciative remarks regarding the Board made by the Secretary of the Navy.

American Engineering Standards Committee.—One of the most important results of the movement for closer coöperation between engineering bodies has been the formation, in 1917, of the American Engineering Standards Committee, whose object is to unify and simplify the methods of arriving at engineering standards; to insure coöperation between the different societies; and to prevent duplication of work. At the present time many bodies are engaged in the formation of standards and there is no unanimity in the rules. The present committee is composed of three representatives of the American Society of Civil Engineers, the American Institute of Mining Engineers, the American Society of Mechanical Engineers, the American Institute of Electrical Engineers, and the American Society for Testing Materials.

Woman's Auxiliary.—At the meeting of the Institute in February, 1917, the ladies present united in forming the Woman's Auxiliary of the Institute. This has been passing through a period of organization for service and, in addition to these executive activities, involving as they do the formation of local branches in various parts of the country, the Woman's Auxiliary has raised $12,000 for Belgian Relief, has twice sent consignments of gifts to American engineers serving in France, has contributed about $1000 in money to the 11th Engineers, U. S. A., has collected and sent help to the stricken residents of Halifax, and carried on other work which has been reported in the Bulletins for April, July and September, 1917, and January, 1918. At the present time the New York branch is actively taking up work for the year 1918, and the spirit in which the movement is inaugurated augurs well for the success of the efforts. It has also adopted some French orphans.

British Ministry of Munitions.—On November 13, 1917, the Founder Societies gave a dinner to the Special Commission of British Ministry of Munitions to the United States, thus giving an opportunity for the distinguished visitors to explain at length the methods and results accomplished by our English cousins in the important industrial side of carrying on a great war.

Membership.—The report of the Membership Committee is given

REPORT OF

Assets

Cash on Hand and in Bank:			
General funds		$8,577.51	
Special funds		1,887.62	$10,465.13
Investment of "Life Membership" Fund:			
$2,000 Interborough Rapid Transit 5 per cent. Bonds due 1966		1,974 31	
$1,000 Illinois Central, Chicago, St. Louis & New Orleans R. R. 5 per cent. Bond due 1963		1,010.56	
$2,000 Chicago, Milwaukee & St. Paul R. R. 4 per cent. Bonds due 1934		1,877.63	
$1,000 Chicago, Milwaukee & St. Paul R. R. 4½ per cent. Bond due 2014		824.25	5,686.75
Interest in United Engineering Society:			
Land at 29 West 39th Street—⅓ of $540,000		180,000 00	
Building at 29 West 39th Street—⅓ of $1,050,000	$350,000.00		
Addition during 1917	12,500.00	362,500.00	
Equity in Real Estate Equipment		3,346.62	545,846.62
Library:			
Books and Periodicals in Library belonging to the American Institute of Mining Engineers			40,000.00
			$601,998.50

Receipts

Dues, Etc.:			
Initiation Fees		$8,580 00	
Annual Dues:			
Current	$63,290.94		
Arrears	2,273.73		
Advance	2,138.23	67,702 90	$76,282.90
Receipts from Other Sources:			
Sale of Transactions		4,413 76	
Sale of Binding		11,595 55	
Sale of Advertising		5,573.13	
Sale of Special Editions		518.40	
Sale of Bulletins and Pamphlets		2,955.45	
Sale of Pins and Fobs		340.50	
Subscriptions to Land Fund		15.00	
Interest on Investments and Deposits		772.90	
Collection of Checks		202.67	
Refund from St. Louis Meeting		75.95	
Refund from Chicago Section	$ 17 94		
Refund from Columbia Section	109.50		
Refund from Montana Section	1.60		
Refund from Nevada Section	127.50		
Refund from Puget Sound Section	128.50	385.04	
Refund from Committee on Mining Geology		5.00	
Sundries		797.45	27,650.80
Special Funds:			
Life Memberships		1,500.00	
Hadfield Prize Interest		38.27	
Thayer Prize		1.57	
From the Dinner Committee, 1917 New York Meeting		247.30	
Liberty Bonds Purchased for Employees		1,150.00	
From the Special Finance Committee, 1917 New York Meeting		212.56	3,149.70
Total Receipts			$107,083.40
Cash on Hand January 1, 1917			5,750.00
			$112,833.40

THE TREASURER

Liabilities

Special Funds:			
Hadfield Prize and Interest		$1,120.64	
Thayer Prize and Interest		56.43	
Dinner Committee		247.30	$1,424.37
Reserve for Life Membership Fund			40,000.00
Life Membership Fund:			
Balance, January 1, 1917		$4,650.00	
Additions during year 1917		1,500 00	6,150.00
United Engineering Society:			
Balance due on A. I. M. E. share of additions to building 29 W. 39th St., $12,500 less $5,000 paid			7,500.00
Surplus:			
As at January 1, 1917		537,183 79	
Add: Net Income year 1917		9,740.34	
Balance December 31, 1917			546,924.13
			$601,998 50

Disbursements

General Funds:			
Editorial and Office Expense		$28,539.51	
Treasurer's Account		1,080.82	
Technical Committee		119.52	
Advertising		2,773.86	
Library		4,655.00	
Meetings		2,872.92	
Local Sections		3,147.13	
Committee on Increase of Membership		2,615.00	$45,794.76
Printing, Etc.:			
Transactions 1917	$9,528 48		
Transactions 1918	4,520.47		
		14,048.95	
Bulletin		17,858.42	
Binding Transactions 1917		7,653.88	
Special Editions		436.08	
Back Volumes		1,984.50	
Circulars		527.18	
Year Book		1,413.74	
Miscellaneous		2,843.50	46,766.25
Special:			
Invested Account, Life Membership		1,762.35	
Liberty Bonds		1,150.00	
Thayer Prize Award		50.00	
Finance Committee, 1918 N. Y. Meeting		212.56	
Addition to U. E. S. Building—proportion		5,000.00	
Alteration to 5th Floor–proportion		1,632.35	9,807.26
Total Disbursements			$102,368.27
Cash on Hand January 1, 1918			10,465.13
			$112,833.40

in this volume and this matter will also be discussed more at length by the President of the Institute.

Meetings.—Two meetings were held during the year, in accordance with recent custom, and the attendance at both attained a record to date. The February Meeting in New York is reported in detail in Vol. 56, and that of October, at St. Louis, in Vol. 57.

Publications.—The publications have been continued on the same scale as formerly, there being, however, a rather important change in the news section of the Bulletin, all of which is described in the report of the Committee on Publications.

Library.—The report of the Library Committee gives details of the year's work, which has been an unusually important one, both on account of securing the services as Director of the Library, of Harrison W. Craver, a man of wise judgment and ripe experience, and also because of the usefulness of the services which the library has been able to perform for the Government in the present crisis.

Employment Department.—Important progress has been made in the results accomplished by the employment department and, while we still hope for a greater interest in this department among both employer and employee members of the Institute, it is gratifying to record an increase in the service.

Local Sections.—Two new local sections have been established during the year; namely, the Nevada Section and the Tulsa, Okla., Section. Under this heading it is also appropriate to mention the formation of the Engineering Societies Club of Hawaii, to which members of many engineering societies are eligible. An announcement is made in the Bulletin for December, 1917, page xlv.

Affiliated Student Societies.—The work of the Committee on Junior Members and Affiliated Student Societies has resulted in a still closer coöperation between the Institute and the student bodies. Addresses have been made to some of the student societies by both the President and Secretary of the Institute, and the societies have been more regular in supplying the Editor of the Bulletin with information of their activities.

President's Prize.—The President's Prize offered for the best paper published by the Institute, and written by a Junior Member or Member of an Affiliated Student Society, was awarded in 1917 to J. J. Beeson, as of the year 1915. The prize was offered by President Thayer in 1915 but, owing to an error, Mr. Beeson, who had presented the best paper under the rules, was not recognized at that time as a Junior Member.

Coöperation With Other Bodies.—The Institute coöperated with the Chamber of Commerce of the United States, as announced on page ix of the Bulletin for February, 1917. It also coöperated with the New York Stock Exchange by assisting in formulating rules for the listing of companies operating petroleum and gas wells. It is also coöperating with other societies, as well as giving information of benefit to its members, by publishing each month a list of forthcoming meetings of sister associations. It has also been represented, as formerly, at meetings of many sister societies and has invited sister societies to send representatives to its meetings.

Washington Medal.—At the request of the Western Society of Engineers, the Institute has two representatives upon the committee which awards annually the Washington Medal.

COMMITTEE ON MEMBERSHIP

The total number of applications brought before the Committee during the year 1917 was 888; the total number of persons who were elected and became members of the Institute during the same period was 1023.

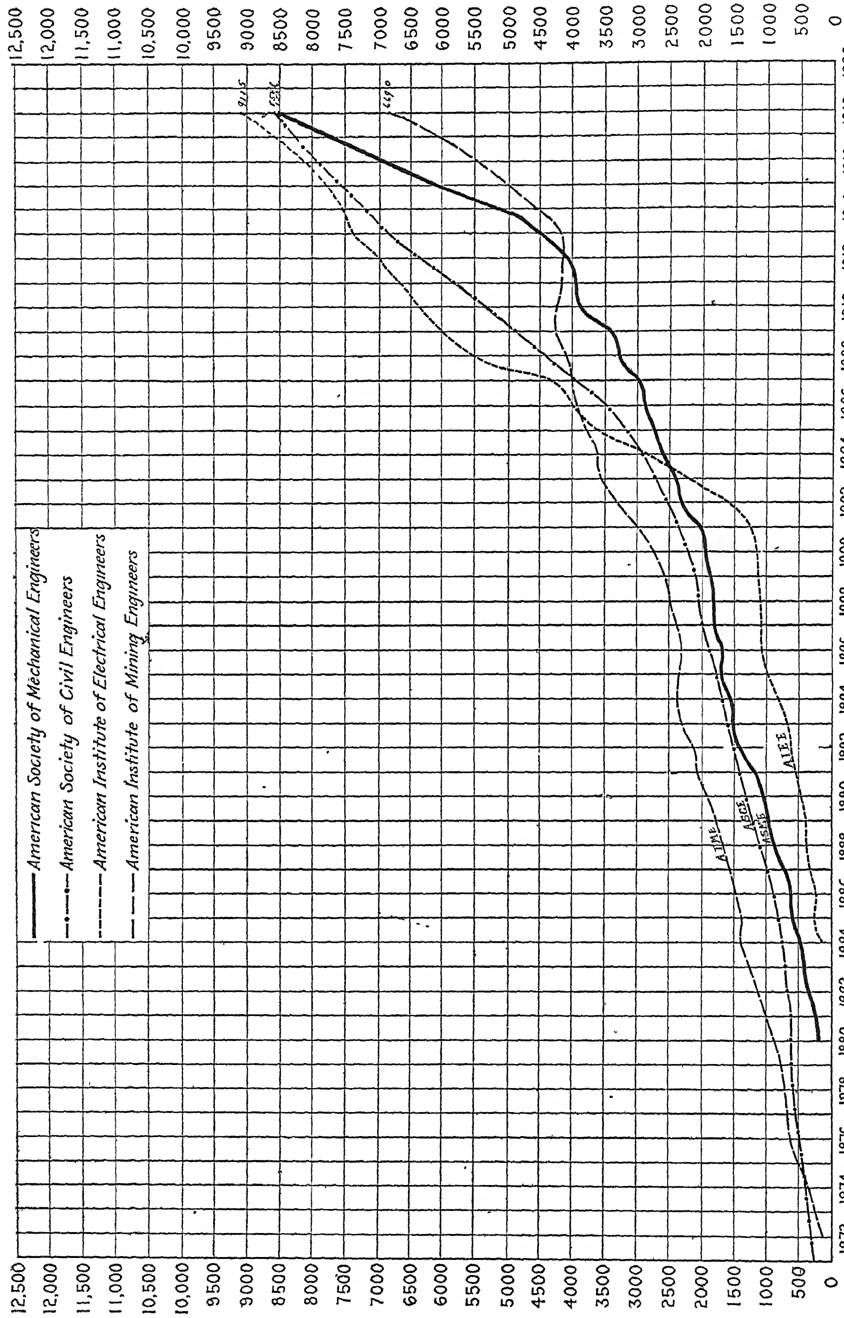
The total membership of the Institute on Dec. 31, 1917, was 6528, consisting of 20 Honorary Members, 5835 Members, 237 Associate Members, and 440 Junior Members. The changes in membership during the year are shown on the accompanying schedule.

Total membership, Dec. 31, 1916		5,781
Loss by resignation	52	
Loss by suspension	206	
Loss by death	67	325
		5,456
Elected	1,023	
Reinstated	49	1,072
Membership, Dec 31, 1917		6,528
Change of status:		
Members to Honorary Members	1	
Associates to Members	2	
Junior Members to Members	14	

COMMITTEE ON INCREASE OF MEMBERSHIP

The work of this Committee has proceeded along much the same lines as last year, and efforts have been continuous to secure a more effective coöperation with committees appointed by the local sections. This has been especially effective in the St. Louis and Columbia (Spokane) Sections; during the coming year it is hoped to have a number of other sections coöperating in an equally effective manner. The work of the Committee during the past 5 years has conclusively demonstrated that the only effective way to interest prospective new members is through personal contact with them. It is also necessary to have some personal knowledge of a man's experience and reputation before approaching him, since it has been our practice not to seek to interest any man unless it seems certain that he will be passed upon favorably by the Membership Committee.

It may be well again to emphasize the difference in function between these two committees; the duty of the Committee on Increase of Membership is to interest worthy men in the work of the Institute and induce them to make application for membership. After their applications are received they are submitted to the Membership Committee, which may require proof of education and experience. Heretofore the Membership Committee has not had any specifications to govern it in its rulings on the qualifications of a member, and has had to adopt standards of its own making. Our committee has coöperated by avoiding the soliciting of applications from men unless it was reasonably certain that they would meet these requirements. Except in the matter of age limits, for which we had no constitutional sanction, the standards maintained by the Committee on Membership have been approximately the same as those now submitted to the membership for vote as a constitutional amendment. The


American Society of Mechanical Engineers
American Society of Civil Engineers
American Institute of Electrical Engineers
American Institute of Mining Engineers
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sentiment for such an amendment has been growing for some time and has now finally crystallized. The many members of this committee who have aided in bringing the matter up for definite action at this time have done an effective service toward increasing the prestige and influence of the Institute.

The number of applications secured, which promised, in the first half of the year, to exceed all previous years, somewhat declined in the second half, the final result being only slightly less than last year. The four autumn months are usually most productive of applications for membership, as the meetings outside New York attract the attention of operating men who are too much occupied with their work to travel far to attend a meeting; and many men also send in applications at that time in order to complete the formalities of election at the beginning of the year. The autumn months this year were so full of uncertainty, and many of our members were so occupied with work in connection with the draft, Liberty Bonds, and the Red Cross campaign that the interesting of new members has been at some disadvantage. Now that we are somewhat adjusted to the unusual activities incident to the war, it is to be hoped that this useful work will hereafter proceed at its former rate.

In concluding 5 years service on this Committee, the Chairman wishes to extend hearty thanks to the many busy men throughout the country who have given generously of their time in forwarding the work, and to bespeak, on behalf of the Institute, equally generous coöperation through the coming year.

Thomas T. Read, *Chairman.*
W. H. Shearman, *Secretary.*

COMMITTEE ON PUBLICATIONS

Three volumes of Transactions were published in 1917: LIV, LV and LVI. On account of delays in printing, Volume LVI was not distributed to the members until early in 1918, but was sent to all members whose dues for 1917 were paid. Printing delays, while very inconvenient, are unavoidable at present, on account of the scarcity in labor, and pressure of Government work.

A collective index of Volumes XXXVI to LV, inclusive, was also prepared during the year 1917; but, again on account of delays in printing, will not be ready for distribution until early in 1918.

For the St. Louis meeting, 82 papers were received, of which 65 were accepted and printed, or 79 per cent. of those received. For the New York meeting, February, 1918, 64 papers were received and 50 were accepted, or 77 per cent. The large proportion of papers accepted, notwithstanding the very searching test given by the Committee on Publications, is an indication of the high grade of manuscripts submitted.

The Bulletin has contained many more items of timely interest than in former years. This is due to intentional expansion in this respect, and also to the circumstances that many activities of the Institute in connection with the Nation, and the closer coöperation between engineering societies, has afforded much more opportunity for items of interest in the form of news. It is much to be desired that members of the Institute form the habit of reading the news section of the Bulletin.

Bradley Stoughton, *Chairman.*

THE LIBRARY COMMITTEE

Since the libraries of the American Society of Civil Engineers, American Institute of Mining Engineers, American Society of Mechanical Engineers, and American Institute of Electrical Engineers, are now combined in one joint library, known as the United Engineering Society's Library, the following report will cover the joint library.

The service that a library gives to visitors is only one of its activities. In our case, dealing as we do with the members of one profession, scattered over the entire world, personally very busy, and usually in need of immediate information, the assistance rendered to those unable to visit the Library is very important, and the work done by mail and telephone becomes no inconsiderable part of the total labors of the staff. The inquiries for searches numbered 465. Most of these have required the making of bibliographies or translations, or the copying of the articles; there are also a great many inquiries requiring less formal treatment, of which no record is kept. Examples are the constant requests for the title of a good book on some subject, or the address of a manufacturer of some machine. These inquiries resemble those received by telephone, and like them use a certain amount of the time of the staff.

The Service Bureau has been frequently called upon by various departments and officials of the United States Government for assistance on many problems connected with the war. Every effort has been made to supply any help in our power, with as much speed as possible. No charge has been made for work of this character.

The importance of the work done for non-visitors can hardly be overestimated and it is gratifying to note the increasing number of such inquiries. The Library Service work has occupied the time of six persons during the year, in addition to that given by the Director to this division of the work.

Books.—At the end of 1916 the Library contained 130,441 volumes and pamphlets. During 1917 have been added 2043 items, making a total on Dec. 31, 1917, of 132,484 volumes and pamphlets. The sources of the acquisitions are shown in the Table.

Accessions during 1917

How acquired	Volumes	Pamphlets	Total
Purchase	939	7	946
Exchange	149	...	149
Gift	721	109	830
Old material	32	85	117
Total	1,841	201	2,042
		Maps	1
		Total items	2,043

Arrangements were made during the year for the publication of brief descriptive reviews of new books in the publications of the Founder societies. The leading publishers of technical books in America have furnished review copies for this purpose, thus enabling us to supply a

comprehensive and timely list of nearly all the important books of interest to engineers and manufacturers, and to perform a service to the members of the societies and the publishers. The books are added to the Library, relieving the book funds to a certain extent.

Visitors.—The number of visitors was 11,371 during the year, an average of 40 daily. Of these 26 per cent. visited the library after 6 p. m. Owing to changes in the building, for the housing of the A. S. C. E., it was necessary to close the reading room for part of July and August, thus reducing the number of readers, notwithstanding that the reading rooms of the three Founder societies were gladly loaned to the Library during this interval.

Director.—The Library was unusually fortunate to secure, on Apr. 1, 1917, the services of Harrison W. Craver, Librarian of the Carnegie Library of Pittsburgh, as Director of the Library. The experience that he brings to his work, comprising as it does extended library work, knowledge of the practice of engineering, great energy and wise judgment, has been a potent factor in the progress of the Library during the year, and in the successful amalgamation of the large library added by the incoming of the A. S. C. E. into the fold of the Founder societies. A brief sketch of Dr. Craver was published in the Bulletin for May, 1917.

Equipment.—The Library is now housed on the 13th floor and part of the 12th floor of the building. As soon as the books can be moved, the Library will occupy the whole of the 13th and 14th floors.

Sale of Institute Publications.—The sale of Institute publications during the year 1917 is given below, together with the corresponding figures for 1916:

	1916	1917
Sale of Transactions	$3,237.07	$4,413.76
Sale of special editions	1,722.50	518.40
Sale of Bulletins and pamphlets	2,263.95	2,955.45
Total	$7,223.52	$7,887.61

E. Gybbon Spilsbury, *Chairman.*

PAPERS

Biographical Notice of Franklin Guiterman

BY ROSSITER W. RAYMOND

FRANKLIN GUITERMAN was born March 7, 1856, in Cincinnati, Ohio, where his father, William Guiterman, was at that time engaged in the wholesale dry-goods business. Both of his parents were natives of Bavaria, but the inspiration of America was upon them, as they gave to their son a peculiarly American name, symbolizing thrift, individualism and scientific knowledge.

Franklin Guiterman received his general education in the grammar schools and the Hughes High School of Cincinnati. He finished the latter course in the early 70's of the last century, when the great demand for mining and metallurgical experts in this country naturally led his parents to direct his further studies in that direction. Accordingly, he went to Europe, and studied at the Royal Saxon Mining Academy of Freiberg, where he completed the course in 1877, at the age of 21, and returned to the United States to engage in mining and metallurgical practice.

Going to Colorado, he became assayer for the Terrible mine, at Georgetown, and in 1878, for the Little Chief mine at Leadville. The position of assayer, particularly at that period and in that region, was the door to much valuable knowledge of mines and ores. Besides learning the nature and value of the different classes of ore from the mines of his own company (if he was employed by a company) the assayer had the first chance, through his outside customers, of seeing and testing the specimens brought by prospectors, and thus learning of important new discoveries. Moreover, if he possessed metallurgical knowledge, he might advance to the position of a metallurgical manager. Guiterman stayed in Leadville four years, and during that period was assayer or chemist for several different companies. Then for about a year he superintended copper-mining operations at Hartville, Wyo. In 1884, he had charge of sampling works at Silverton, Colo.—an admirable opportunity for gaining wide knowledge of the varied ores of the San Juan country. In 1885, he was Superintendent of the Mingo plant of the Pennsylvania Lead Co., at Sandy, near Salt Lake City, Utah.

The foregoing list of employments, each occupying not more than a year, certainly looks like the history of a rolling stone, gathering no moss. But the cause of these frequent changes was not inefficiency in each new position. In that time and period, a man who lost his place for such a reason was not likely to get another in the same neighborhood right away. And as for gathering "moss," the kind of "moss" that

Guiterman gathered was, during this period, knowledge and experience, rather than money. No doubt he was restless and impatient of control, though always faithful, tireless and exact in his work. It was characteristic of him that in the brief intervals between official engagements, he spent his time in metallurgical investigations, performed in the laboratory of his friend, E. E. Burlingame, of Denver.

After eight years of this apparently but not really desultory preparation, the period of longer engagements and larger responsibilities began. From 1886 to 1893, Mr. Guiterman was connected with the W. J. Chamberlain Co., in the buying and selling of ores and the management of sampling works. This business is intermediary between the miners and the smelters; and it is a highly honorable feature of Guiterman's record that his management of it commanded the confidence and esteem of both parties, as was forcibly evidenced in his unanimous election to be the director of the Smelters' Clearing House Association in 1894. This Association had but a short life. It was dissolved in 1895, but not before Guiterman had introduced a scientific system for the classification of ores, which has been adopted very generally by American smelters, both in quoting commercial prices and also in preparing furnace charges for economic metallurgical practice.

From 1895 to 1899, he was General Manager of the Durango plant of the Omaha and Grant Smelting Co.—a position presenting considerable technical difficulties, in which he achieved a conspicuous success, and which he had until 1899, when, upon the organization of the great American Smelting and Refining Co. and its acquisition of the Durango works, he became and remained for two years, General Manager of the large Pueblo plant. When the "Guggenheim interests" became part of the American Smelting and Refining Co., he was promoted to be General Manager for the Colorado department.

During his very successful management of the Pueblo plant, he realized the dependence of the smelting works upon the price of coke as fixed by the producers, and his efforts to diminish or remove that dependence led to the formation of the Carbon Coal and Coke Co., and the establishment at Cokedale of a model coal-mining and coke-manufacturing industry. These marked successes were rewarded by further promotion. He became General Manager of all the Guggenheim plants in Colorado, including that of the United States Zinc Co. He was also made a Director of the American Smelting and Refining Co., and also of the American Smelters' Securities Co., and in March, 1912, he was called to New York, as Director General of the former company. After establishing himself at headquarters, he became also President of the Chesapeake & Ohio Coal and Coke Co. and of the New River Collieries Co., for which positions his Colorado experience with coal and coke, together with his extraordinary executive ability, abundantly

qualified him. It was in connection with this new sphere of activity that, during an inspection of coal mines in West Virginia, he caught a cold which developed into pneumonia, and of which he died at St. Luke's hospital, New York City, on Sunday, May 3, 1915.

Mr. Guiterman became a member of the Colorado Scientific Society, July 7, 1884; was elected its Secretary in 1891 and held this office until 1896, when he left Denver, to become a resident of Durango, Colorado, at which time his active interest in the Society temporarily ceased. In 1907, his home again being in Denver, he resumed a lively interest in the affairs of the Society and was elected its President in 1908, which office he held for two consecutive terms.

From a memorial published by the Society, the following paragraphs are taken:

"During his secretaryship many valuable papers were presented and the Society made great progress and growth, and the same good results were shown during his presidency. The records show a number of very valuable papers prepared and read by him, among which we mention "The Determination of Iron and Copper in Ores and Furnace Products," "Gold Deposits in the Quartzite Formation of Battle Mountain, Colorado" and "On the Use, Non-Use and Waste of the Mineral Resources of Colorado," besides contributing written discussions on several other papers. His administration as President was marked by the presentation of able and valuable addresses on a number of scientific subjects, and as presiding officer he was a premier in bringing out discussions and obtaining thoughtful expressions from different view-points and in emphasizing the practical conclusions to be drawn.

"The Society is deeply indebted to him for obtaining its present home, for a number of cases for shelving its books and for a valuable stereopticon outfit, and above all for the inspiration of his scientific knowledge and learning, his untiring energy and his ever thoughtful consideration of the best interests of the Society.

"The Society never had a more loyal member."

Mr. Guiterman was elected an Associate of the Institute in February, 1877, being at that time a student at the Freiberg Mining Academy in Saxony. In 1906, he became a member. He married in 1886, Miss Mary B. Sproat of Taunton, Mass., who survives him, together with one son, Kenneth S. Guiterman, already a member of the Institute.

Socially, he was a member of the University Club, New York City, and the Denver Club, the Denver Country Club, and the Denver Athletic Club, of Colorado.

His death in the prime of life, surrounded by congenial activities, crowned with past triumphs, bright with prospects of further usefulness and honor, and rich with associations of personal affection, was a severe loss to his fellow citizens, his technical colleagues, and a host of friends.

The Chilean Nitrate Industry

BY ALLEN H. ROGERS, B. S., BOSTON, MASS., AND HUGH R. VAN WAGENEN, E. M , PIOCHE, NEV.

(New York Meeting, February, 1918)

THERE are few natural monopolies comparable with the nitrate industry. Perhaps the only other one is, curiously enough, also an essential fertilizer material, *viz.*, potash, of which the Germans have heretofore held practically a monopoly due to the existence in their territory of the most important known deposits of potash salts. And although nitrates in minute amounts are found in many desert regions, the only deposits capable of being worked commercially exist in Chile.

Combined nitrogen in the oxidized form is an essential for plant life. Nature provides it mainly through the agency of nitrogen-fixing bacteria. But where lands are cropped artificially this supply is too small, and gradually the nitrogen supply becomes exhausted. In order to continue farming, it is necessary to furnish a supply of nitrogenous plant food, and this is done by putting on various substances containing combined nitrogen. These consist of various animal wastes, ammonium sulphate, the ammonia of which is obtained in the destructive distillation of coal, and Chile saltpeter. The latter is immediately available as a plant food, the nitrogen being in the required form. The other substances must oxidize before they are available. Besides its use as a fertilizer, Chile saltpeter is the source from which the bulk of the nitric acid of commerce is derived. The use of nitric acid in the manufacture of almost all modern explosives is, of course, well known.

IMPORTANCE OF THE NITRATE INDUSTRY

Chilean nitrate, the existence of which was first mentioned in 1809, is said to have been first exported in 1830. Only a few thousand tons per annum were exported for some years, but the amount gradually increased until, in 1879, when the Chile-Peruvian war began, the export amounted to about 300,000 tons. This nitrate was largely produced from the Province of Tarapaca, until then, Peruvian territory. By the terms of peace with Peru in 1884, this province, as well as Tacna, became Chilean. The Bolivian Province of Antofagasta was also acquired as a result of this war, and thus Chile, with the deposits in her own territory, acquired control of the whole supply of nitrate. At the present time, exports are approximately 3,000,000 metric tons per annum, having a

value at point of embarkation of about $50 per ton at present, or a total of $150,000,000. The nitrate industry, measured in value, is thus of great importance.

Naturally, on a country so small as Chile, the economic influence of this industry is very large. First, as affecting the country as a whole, is to be noted the export tax. This is at the rate of 28d. sterling per Spanish quintal (46 kg.), and is at present amounting to over £7,000,000

TABLE 1.—*Nitrate Exports, Spanish Quintals*

Port	Railway	1913–14	1914–15	1915–16
Iquique	Nitrate Rys. Ltd	12,461,367	6,874,995	10,930,460
Coleta Buena	Agua Santa Co	5,960,927	3,404,368	5,053,784
Junin		1,470,200	1,098,298	1,069,905
Pisagua		2,530,613	839,454	1,615,691
Tocopilla	Anglo-Chilean N. & Ry. Co.	7,901,523	3,267,412	7,170,621
Mejillones	F. C. A. B.	7,679,607	5,884,170	9,759,190
Antofagasta	F. C. A. B.	9,842,484	6,129,394	10,585,895
Coleta Coloso	F. C. A. B.	4,189,141	1,814,005	3,423,671
Taltal	Taltal Ry. Co.	6,715,429	2,758,618	5,677,176
		58,751,291	32,070,714	55,286,393

per annum, or, say, $35,000,000. From 1880 to 1909 inclusive, the Government collected on account of this tax £81,000,000 and, during the 7 years since, it must have collected some £40,000,000 more The revenue from this tax constitutes about 40 per cent. of the total revenue of the Chilean Government.

Some very interesting studies of the industry published by Alejandro Bertrand, of the Nitrate Propaganda Association, give the following facts for 1910: The coastwise traffic, by which the bulk of the internal commerce of Chile is carried on, was engaged to the extent of 49 per cent. of the total in supplying the nitrate ports with food products raised in the

TABLE 2.—*Nitrate Production, Exports, Etc., Spanish Quintals*
(Year Ending June 30)

	1912	1913	1914	1915	1916
Production	54,572,965	59,450,462	62,322,617	34,091,243	57,715,614
Exports	54,254,471	58,492,372	58,751,291	32,070,714	55,285,814
To Europe and Egypt	41,407,349	43,051,680	44,534,131	16,939,650	29,017,771
To East Coast U. S.	9,896,768	12,336,221	11,222,657	12,295,221	20,390,839
To West Coast U. S.	1,086,933	1,056,778	1,068,125	1,142,197	3,094,003
Various	1,863,421	2,047,696	1,926,378	1,693,646	2,783,195
Stocks on Coast	13,854,000	13,423,000	16,656,000	18,000,000	19,318,000

south; the nitrate exported constituted 71 per cent. of the value of all exports, and the value of the nitrate was 23 per cent. of the value of the products of all industrial operations of the country, including agriculture and mining. On the other hand, only 7.3 per cent. of the total population of the country lived in the nitrate regions, although 38 per cent. of the total wages of the country, except those paid in agriculture, were paid to the laborers employed in the nitrate industry, who were 8.5 per cent. of the total laborers of the country. These figures are almost paradoxical and are accounted for by the peculiar conditions under which the nitrate is found, and under which the work must be carried on.

Situation and Character of the Deposits

Chile is a country of peculiar shape. Reaching from south latitude 18° to 56°, a distance of about 2600 statute miles, in its greatest extent from east to west it is only about 250 miles wide, while much of it is little over 100 miles in width. As it borders the Pacific, this means that in all parts it is close to the ocean. But the northern part rises abruptly from the coast, so that it is not easy to construct lines of transportation. In this portion, a range of mountains attaining altitudes of 3000 to 6000 or 7000 ft. rises abruptly from the coast. Between this range and the main ranges of the Andes are broad valleys gradually rising to the foothills of the latter. The coast is washed by the Humboldt current, an ocean stream having its source in the Antarctic, and when the winds blow toward the land they are cooled by the cold water to a temperature below that of the land, so no moisture precipitates. Winds from the east are forced to high altitudes by the Andes, and hence deposit their moisture on the east side of these mountains. As a result, the coast and the valley east of the coast range receive practically no moisture, making them what is perhaps the driest region in the world. We think of our southwest as a desert, but a great variety of desert plants grow there and in considerable profusion. In the Atacama desert of Chile, it is no exaggeration to say that there is no vegetation. On the tops of the coast range toward the sea there is sometimes a sparse growth of cactus which gathers moisture from the fogs, but in the valleys on the other side there is absolutely nothing.

It is in such circumstances that the *caliche* is found. Caliche is generally a cemented gravel, the cementing material being sodium nitrate and other salts which accompany it. In the early days of the industry, and to some extent at present, such material was denominated *costra*, the term caliche being reserved for practically pure nitrate, or nitrate accompanied only by soluble salts. Now, as a general rule, any nitrate-bearing material is termed caliche, that composed of soluble salts entirely being called *caliche blanco*, or white caliche.

The region in which the caliche is found extends from 19° 30′ to 26° south latitude, embracing the provinces of Tarapaca and Antofagasta. A little is found in the northern part of the Province of Atacama, but

TABLE 3.—*Nitrate Production by Districts, Spanish Quintals*

Regions	1913–14	1914–15	1915–16
Tarapaca	24,686,930	10,954,482	22,083,321
Tocopilla	8,114,230	3,517,530	7,088,655
Antofagasta	18,567,730	14,811,694	20,436,566
Aguas Blancas	3,763,156	1,183,650	2,685,222
Taltal	7,190,571	3,623,887	5,421,850
Total	62,322,617	34,091,243	57,715,614

practically all the production comes from the two former provinces. In the valleys between the coast range and the foothills of the Andes, the very bottoms are frequently occupied by beds of sodium chloride, forming the *salares*. These deposits often contain sodium nitrate, sometimes in sufficient quantity to pay for working. As a general rule, the caliche is found on the gentle slopes which rise from the central depressions containing the salt. These deposits are frequently of great extent, running into areas of hundreds and even thousands of acres.

The caliche is thus a blanket formation, the major dimensions of which are parallel, or practically parallel, with the surface. It is never found outcropping except in rare instances where the caliche bed has been cut by a water course. It is almost invariably covered by more or less material which, at the surface, is of a peculiar puffy consistency, much like a soufflé. The caliche may occur immediately below this material, at a depth of 6 in. to 1 ft. (15 to 30 cm.) or there may be further layers of barren material, in which case the latter will often be partly cemented by salts, generally sodium sulphate. The top of the caliche will be found at depths varying up to as much as 20 or 25 ft., but the average depth of overburden is about 2 to 3 ft. (0.6 to 0.9 m.).

The caliche itself is of varying thickness, sometimes being but a few inches and again 4 or 5 ft. or more. The percentage of sodium nitrate varies up to practically pure nitrate; the latter material is generally found as a fissure-filling in solid rock, but there are places where very high-grade material occurs under gravel, apparently having crystallized primarily without any covering.

The caliche generally does not lie on bed rock, but is most commonly underlain by loose unconsolidated fine gravel or sand. In some sections, the caliche consists of nitrate impregnation of rock fragments which represent the disintegration of the underlying rock, which have not been

transported. In such cases, the percentage of nitrate decreases with depth and with the lessening degree of decomposition which the underlying rock has undergone.

Origin of the Nitrate

It seems quite evident that the caliche is a travertine-like deposit quite similar in origin to the material which occurs so extensively in the southwestern United States and Mexico, where it is also sometimes called caliche by Mexicans. That is to say, it is due to the deposition of the salts from capillary circulation. In spite of the almost absolute dearth of precipitation in the nitrate *pampa,* there is a great deal of underground water which is highly saline. This water is, undoubtedly, supplied from the summits of the Andes to the east, although its circulation is probably very slow. Portions of it are probably drawn up to near the surface by capillarity, carrying with it the salts in solution, which are deposited by the rapid evaporation induced by the extreme dryness of the atmosphere. This action is probably proceeding now in some sections, although in other parts it has ceased. The separation of nitrate from the sodium chloride, as previously described, is perhaps due to rain which occurs at rare intervals. Such waters would tend to collect in the depressions, and the nitrate, due to its somewhat deliquescent nature, would tend to creep up from the depressions, thus resulting in a separation of the nitrate from the salt and its deposition on the slopes above.

As to the primary origin of the nitric acid in the nitrate, a great many ideas have been advanced. Some have assigned it to original deposits of guano, others to guano transported from the coast in dust by winds. Both of these ideas seem untenable, due to the fact that there is practically no phosphoric acid present. There is a theory which ascribes its origin to seaweed, its main support lying in the fact that iodine occurs in the caliche. General geological considerations make this theory of its origin very unlikely. There is also a theory which ascribes the nitric acid to the action of bacterial organisms. A great many students of the subject support this theory, but it seems to us untenable for the reason that, so far as known, where these organisms are working there must be vegetation, and where vegetation exists there must be precipitation of moisture. The nitric acid so formed, therefore, must either be consumed by the growing vegetation or removed by drainage. Recently Courtney DeKalb[1] advanced the idea that the nitric acid was derived from volcanic eruptions, and pointed out that, in the nitrate regions, the major portions of the deposits were underlain by tuffs. W. L. Whitehead,[2] who has recently made a study of the nitrate deposits, supports this theory. As further proof he shows that the nitrate is most concentrated in areas

[1] *Mining and Scientific Press* (May 6, 1916), **112**, 663.

[2] Private communication.

underlain by certain tuffs, other formations showing only sporadic occurrences. Finally, there is the theory which ascribes the fixation of the nitrogen to atmospheric electrical discharges. This idea seems to us the most plausible of all, when it is considered what large amounts of fixed nitrogen are brought to the earth's surface by rain. Clark[3] gives a table showing the quantities of nitrogen falling upon the earth's surface in eight widely distributed localities. These amount to from nearly 4 to above 9 lb. (1.8 to 4 kg.) per acre per annum. Violent electrical storms are extremely frequent in the Andes, and with the precipitation there to gather up the fixed nitrogen and to transport it to the arid nitrate pampas by underground circulation, we have a combination of forces which would very rapidly accumulate the nitrates. The presence of the minute quantities of iodine with larger amounts of sodium chloride, sulphate, and biborate, can be ascribed to the ordinary desert accumulation of which we have so many examples in our own country.

The caliche contains, beside sodium nitrate, sodium chloride, sodium sulphate, potassium nitrate, sulphates of lime and magnesia, sodium iodate, and sodium biborate. Material mined is usually of the following composition:

	Per Cent.
Sodium nitrate	14 to 25
Potassium nitrate	2 to 3
Sodium chloride	8 to 25*
Sodium sulphate	2 to 12
Calcium sulphate	2 to 6
Magnesium sulphate	0 to 3
Sodium biborate	1 to 3
Sodium iodate	0.05 to 0.1
Sodium perchlorate	0.1 to 0 5
Insoluble matter	To make 100 per cent.

* Sometimes 50 or 60 per cent.

The methods of exploitation are somewhat crude, and at first glance seem capable of much improvement. They are practically the same as those of 30 years ago, and while some details have been altered and improved, the work, particularly as regards the treatment end, is still very inefficient. It is mainly on this feature that a great many experimenters are now working.

Prospecting and Sampling

In view of the character of the deposits, it is obvious that methods somewhat similar to those used for prospecting gold placers are applicable to caliche deposits. Formerly pits were sunk at random intervals. More recently the pits are sunk at regular intervals, and in the average

[3] *Data of Geochemistry*, 46.

deposit, a pretty accurate determination of the contents of the ground can be obtained. Usually, if the deposits are extensive and of fairly uniform tenor, an interval of 100 m. (328 ft.) or even more, is adopted. Thus, one hole is put down to every hectare, or 2.47 acres. In spotty country, smaller intervals are adopted. The pit is sunk by pick and shovel through the overburden to the top surface of the caliche, and is about 3 ft. (0.9 m.) in diameter, or as small as the workman can conveniently make it. Through the caliche, which is generally quite hard and firm, a hole is then sunk with a pointed bar, aided by small charges of dynamite if necessary. This hole is not over 1 ft. in diameter, and can be sunk about 6 ft. in depth; if the bottom of the caliche is not then reached, it is necessary to widen the *tiro* by charging with black powder. After cleaning out, the small-diameter tiro is continued. The caliche excavated is set on one side of the hole, apart from the waste, in order that the sampler may observe its character.

In sampling the tiro, the sampler is equipped with a pointed bar and a shovel like a post-hole spoon; he generally, also, has a piece of looking glass to throw a ray from the sun down the hole. The most essential part of his equipment is the *mecha*, a piece of cotton wicking, which is used to determine whether or not the material contains nitrate. This is done by powdering the caliche, and sprinkling the powder over the glowing end of the mecha; the amount of deflagration indicates the grade of the caliche. It is surprising how expert the samplers become in the use of this appliance. The sample is taken from the side of the hole by breaking off pieces of the caliche, which fall to the bottom of the tiro; these are then brought up, any waste in them is sorted out, and the sorted remainder is sent to the assayer. The thickness of the caliche is noted, and an estimate made of the proportion of clean caliche it will yield; these results, together with the assay obtained from the sample, are used by the engineer in estimating his reserves. The reason given for this rather inaccurate practice is that it duplicates the actual work in nitrate extraction. The results are said generally to be low in comparison with the actual nitrate yield of the ground, but this is no doubt due to the factor of safety used. Recently, some of the companies have adopted sampling methods more in consonance with modern ideas.

Mining and Transportation Methods

The losses in mining are high. In deposits of great extent the method pursued is to open long quarry faces, *rajos*, and advance them more or less regularly across the country. Spots of caliche too low in grade to pay are left behind as islands; almost all workings will show this feature, there being few deposits of such even grade as to permit taking everything. For advancing the face, a tiro, such as has been described for sampling, is

put down, and if the caliche appears to be satisfactory, the hole is charged with black powder and fired. The effect of the slow-burning powder is very advantageous for this kind of ground, cracking the caliche without breaking it up much. No attempt to remove any of the overburden is made before blasting. After the shot is fired, the contractor begins sorting the material, shoveling the waste overburden behind him and sorting out the lumps of caliche, breaking up by hammer or bulldozing those that exceed 35 or 40 lb. in weight. The caliche he stacks in an orderly pile, still further back on top of the waste. A ditch is thus carried forward laterally which, in front, is of the depth of the overburden plus the caliche, while behind it is of the depth of the overburden.

Not all workings permit such orderly methods, and where the caliche occurs in detached bodies of comparatively small size and irregular thickness, the work is likely to be very disorderly. In all workings, there is considerable loss of caliche that is pulverized by blasting and handling, the fine caliche not being recovered because it becomes mixed with the overburden. Furthermore, when the tiro put down for blasting shows poor ground, the work at that point is abandoned, and where the bodies of caliche are comparatively small, a fringe of caliche is not recovered. It is not possible to determine accurately what the loss is, as this varies with the character of the caliche, which shatters little when blasted if it is tough and firm, but a great deal if it is friable. In certain of the salar deposits, where the caliche is mainly rock salt and nitrate, the loss is probably as low as 5 per cent. In other instances it may go as high as 25 to 30 per cent.

As compared with such methods it seems as if some of our mechanical digging appliances would be a great improvement. The only American company at present operating in the field has thought so, and has installed a drag-line excavator mounted on a truck of the caterpillar type. With this machine the overburden is stripped from the caliche, but it may be questioned whether any advantage is gained in point of cost, considering the high price of fuel and of the necessary skilled attendance, although there is a distinct advantage in replacing a certain number of men. At deposits of great uniformity and with considerable overburden, mechanical excavation would probably be advantageous, particularly as labor costs increase.

Almost invariably, the quarry work is done by contract. The tiros are sunk by contractors, *barreteros*, prices ranging from 1 to 3 pesos Chilean per foot, or on the average about 30 c. American money. The quarry contractor, *particular*, who generally works independently of the barretero, is paid a certain price per cartload. The weight of a cartload varies considerably, but averages about 50 Spanish quintals, or, say, 2.3 metric tons. The prices per cartload run from as low as 2 pesos to 25 pesos or over, say from 40 c. to $5, according to the tonnage that

must be handled to deliver 1 ton of caliche. In general, these figures work out to a cost of 15 to 20 c. per ton of material handled, sometimes below 10 c. With such low costs by hand labor, conditions must be very favorable to derive any advantage from mechanical appliances requiring high-cost fuel. A further argument against their use is the irregularity and thinness of the deposits; these features imply a "spread-out" condition of operations which is incompatible with the use of mechanical appliances for digging.

Transportation is another feature of the operation which, at first glance, appears crude in the extreme. Most of the caliche is transported in carts hauled by three to six mules, depending on the grades. These carts are heavy, with enormous wheels, and generally carry from

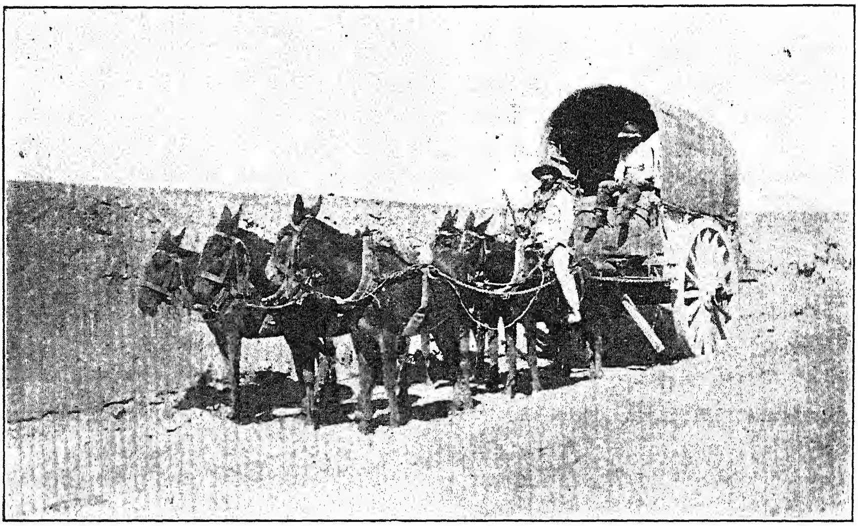

FIG. 1.—CART FOR TRANSPORT.

2 to 2.5 tons. The mules are hitched three abreast, and driven by a man riding the near wheeler. The work is very strenuous for the mules, and they work 8 hr. on alternate days. Their life is comparatively short, and as many of them are employed in the industry, the nitrate pampa is a very fine mule market.

Where the property is small, the caliche is generally delivered to the plant by cart. At large properties, the carts deliver to loading stations on light railways, and these perform the longer haul to the plant. There are a few instances of very uniform deposits where the railway line is kept close to the working face, and the caliche is loaded directly into the cars. Where the caliche is at all spotty or irregular, the carts are invariably used because a single face yields too little to pay for building the railway to it.

Principles of Nitrate Extraction

The treatment of the caliche for the extraction of the nitrate consists in leaching with water. At first thought, it would seem difficult to produce nitrate of any reasonable degree of purity from a material containing so many other soluble salts; fortunately, the solubility of the various salts in the presence of one another is such that this is possible. It will be remembered that the solubility curve of sodium chloride is practically a straight line; that is to say, water dissolves a certain proportion of salt, no matter what its temperature. The solubility curve of sodium nitrate ascends very rapidly with increase of temperature. When the two salts are together, the solubility curve of nitrate still ascends, but that of sodium chloride descends with increased temperature. The same is true of practically all the other salts that are present. Therefore, by adding water to a mixture of these salts and raising the temperature, increasing amounts of nitrate will be dissolved, while the other salts, if already in solution, will be precipitated. Conversely, if a solution of these salts saturated at a high temperature is cooled, the solubility of the nitrate decreases, and the nitrate crystallizes out, while the increasing solubility of the other salts prevents them from depositing.

These are the principles underlying the treatment of the caliche. In practice they are applied by a system of countercurrent leaching whereby the fresh water, which generally already contains considerable sodium chloride, is brought into contact with caliche that has already been leached and is ready to be discharged to waste. From this the solution passes successively through richer and richer charges, its temperature being steadily raised, until finally it is brought into contact with fresh caliche. Here it is given a final boiling, the temperature rising to 107° or 108° C. and the gravity to 1.5, or even higher. It is then drawn off into settling tanks, to separate such slimes as it may contain, and, after clarification, is run into pans where cooling ensues for 8 or 10 days, and the nitrate is deposited. The mother liquor, still containing a large amount of nitrate beside other salts, is returned to the process and enters the cycle generally at the second or third stage of the leaching.

Percentage of Recovery

The caliche treated runs from 14 per cent. nitrate up to as high as 30 per cent. or more. In 1910, Bertrand estimated that the average grade of caliche treated was 22 per cent. but at that time the Antofagasta pampa was not very extensively worked; at present, the large tonnage of low-grade caliche treated in that district will probably bring down the average of the whole industry to below 20 per cent.

The tailings from the tanks average about 8 per cent. nitrate. It is

generally believed that, in Tarapaca particularly, there are immense piles of tailings containing more than 10 per cent. nitrate; in the Antofagasta pampa the manager will generally tell you his tailings run 4 or 5 per cent., but it is more probable that the true figure is nearer 8 per cent. Such losses represent a deplorable state of affairs, but the problem of increasing the recovery is not by any means an easy one.

If a sample of caliche be taken to the laboratory and treated with sufficient water, it is not at all difficult to extract all the salts from the insoluble matter, by repeated washing and filtering. Liberal washing is more important than fine crushing, since the insoluble matter is cemented together by soluble salts. But the use of such an amount of solvent yields liquors which are too weak to give up the nitrate. From the

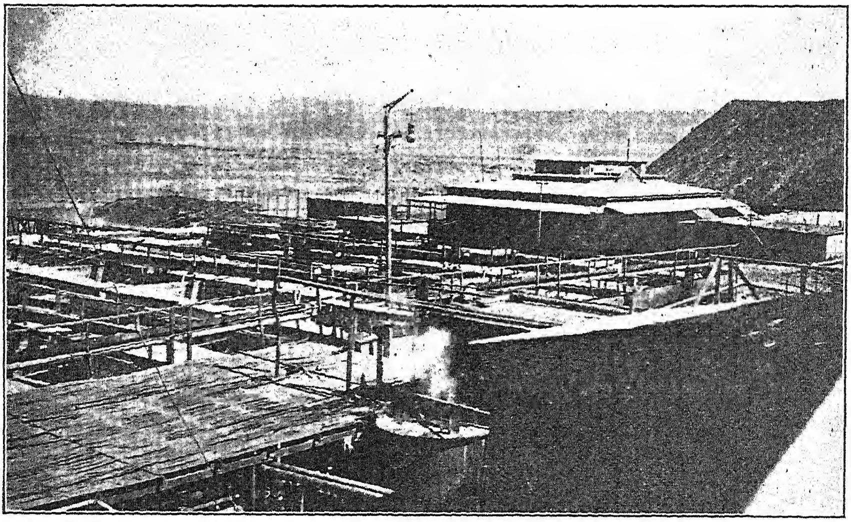

FIG. 2.—EVAPORATING PANS.

preceding description of the principles of the process it is clear that for the production of high-grade nitrate a high degree of concentration at a high temperature is essential. The large amount of solvent required to deliver low-grade tailings therefore entails the production of weak liquors, which can be concentrated only by evaporation. This fact has been long appreciated in the nitrate industry and numerous trials at evaporating have been made. Several scientific installations, including multiple-effect evaporators, have been tried, but failure has always resulted, partly because of the high cost of fuel and partly on account of the corrosion of the evaporating apparatus by iodine. Of course, in the present process, new water is going into the system all the time, but only the same amount as is normally evaporated in the course of the process by boiling in the leaching tanks and exposure in the crystallizing pans. An operator

must take care, under present conditions, that he does not use more wash water than he gets rid of in this way.

Another consideration influencing the recovery is the effect of slime in the leaching operation. Anyone who has an opportunity to examine the tailings can see immediately that a large part of the loss is due to lumps into which the solvent has not penetrated. This is one reason for the discrepancy between the acknowledged and the true assay of tailings. When sampling tailings, a few shovelfuls are taken from the car as it is discharged, and without doubt the men are cautious not to include any lumps in the sample. With the usual coarse crushing, leaching is very imperfect and the charges channel badly. The despair of the nitrate manager is a caliche which slimes badly, thus making a charge impervious; hence they aim to crush as coarse as is consistent with satisfactory recovery, in order to avoid sliming in crushing. With some caliches, a great deal of slime is formed during the leaching operation itself, if the insoluble particles are fine.

Efforts toward improvement in treatment are along two lines. One seeks to find a feasible method of evaporating excess liquors; the other, more efficient washing with a limited amount of water, by the use of filters. The latter involves finer crushing, also, and some good results on a laboratory scale have been reported. At one plant the fines produced in crushing are being separated and treated by a Butters filter. This alters the condition in the leaching tank only to the extent of removing the fines resulting from crushing; it does not prevent the loss due to inefficient leaching nor the formation of fines during the leaching operation. However, according to the results given out, some improvement has resulted. So far as we know, this is the only installation at present in operation, but there are two or three others in course of construction.

Details of Extraction Plants

The plant for carrying on these operations is technically known as an *oficina*, this term covering the whole treatment plant, including all its accessories. The common term when speaking of the leaching plant itself is *maquina*. These plants are often of very high-class construction, steel and concrete being the material most used for modern installations. They generally represent a capital cost of about $3 to $4 per ton of annual caliche capacity. Some of them are very large, a number having capacities of 2000 tons per day, and there are very few the capacity of which is less than several hundred tons per day.

The plant is generally provided with receiving bins, into which the caliche from the railways is discharged. In a few small plants there are no bins, the caliche being dumped in front of the crushers. The crushers are generally of the jaw type, small in size—rarely over 10 by 20 in. and

in plants of large capacity a great many are installed, frequently eight or ten, so that one can always be shut down for repairs. The caliche is crushed to different sizes in different plants, according to its character. Where it is somewhat porous it is reduced to about 3 in. (7.6 cm.); with very dense caliche, the reduction is sometimes down to 1 in. In a few cases the crushed caliche is stored in bins, but it is general practise to receive it directly in cars by which it is transported, sometimes up an incline, sometimes vertically by cage, to the charging stage above the leaching tanks. In one or two instances the material is delivered from the crushers to the leaching tanks by belt conveyer.

The leaching tanks, constructed of heavy sheet steel, are rectangular in plan, from 30 to 35 ft. (9 to 10 m.) in length, 7 to 8 ft. in width, and

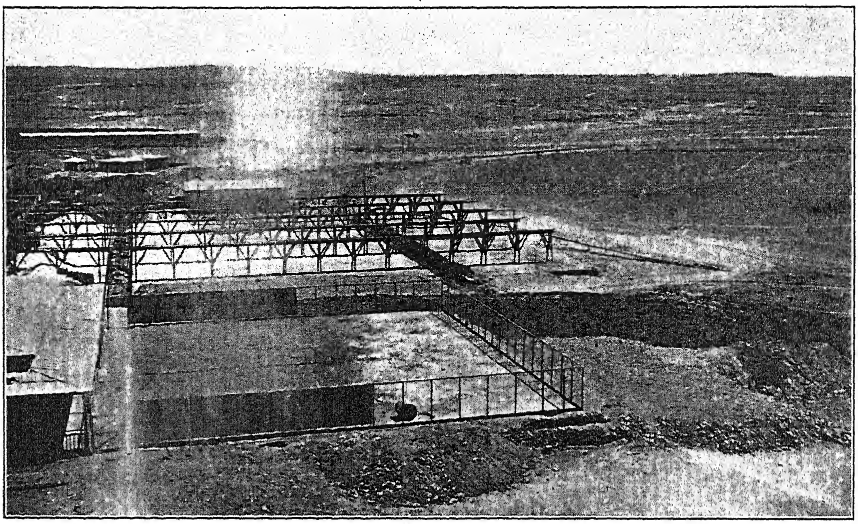

Fig. 3.—Nitrate yard, cleaned up.

about 8 ft. deep. They are provided with a false bottom, punched full of holes, which is raised a few inches above the true bottom, and there are usually three discharge doors for emptying the spent caliche. These tanks are set on trestles 5 or 6 ft. high to afford access for withdrawing the tailings and for the complicated system of piping. They are usually set in batteries of six, all on one level, and piped so that the flow of liquor from the top or bottom of one tank to the top or bottom of any other is possible by means of pumps. The steam piping for boiling the liquors occupies a position along the sides, in the form of a radiator; they are connected in closed circuit with the heating boilers. The tanks hold 60 to 70 tons of caliche, which is charged in at the top. After leaching, the doors are opened at the bottom and the material shoveled into cars which are hauled to the dump by locomotive or cable.

The crystallizing pans, also of steel, in the best plants are also supported on steel trestles. These pans are generally from 15 to 20 ft. (4 to 6 m.) square and about 3 ft. deep, the bottom sloping 6 or 8 in. (15 to 20 cm.) in the length of the pan. In some works, after the mother liquor is drained off, the nitrate that has crystallized is shoveled into a pile at the other end of the pan and allowed to drain for a few days. In most plants, however, wooden aprons are provided above the pans, onto which the nitrate is shoveled for draining. This frees the pan for receiving a new charge during the 2 or 3 days required for draining the nitrate. After this, the nitrate is dumped down to a paved yard, where still further draining and drying goes on before it is ready for sacking and shipment. The sacks hold about 100 kg. (220 lb.).

The boiler plant is a very important feature of the maquina. There are generally two plants, one for the generation of high-pressure steam for power, the other of low-pressure for heating. A few of the newer plants have Diesel engines for power, which is transmitted around the plant electrically. Most of them, however, are driven by steam, the older plants piping it around to the various small engines. For power, all types of boilers are used, but for heating, the Lancashire boiler, carrying about 50 lb. (22 kg.) pressure, is most common. Formerly coal was used for fuel, but recently a great many plants have begun to use oil.

The large plants are well equipped with shops for making repairs, and some of the largest plants even do manufacturing. The Antofagasta Nitrate Co., operating six oficinas in Antofagasta, at one of them has very extensive shops, including a large foundry, and the last year has built all the machinery and equipment for a new oficina.

Labor and Supplies

As each oficina is erected in the midst of a desert, complete provision for housing and supplying the staff must be made. For their men, most companies provide houses built of corrugated iron, built in long blocks. Such houses make the poorest shelter imaginable for the pampa. During the day, with the sun on them, they are ovens, and at night, when the temperature is below freezing, as it generally is in winter, they are very cold. The only excuse for them is that they are cheap, but the few plants which provide mud-brick houses for their men get the pick of the labor. For the manager and his staff very liberal provision is made. The staff houses are very good, frequently palatial, with all sorts of provisions for comfort. It is the custom to make a liberal allowance for living expenses, beside salary. A good deal of abuse grows out of this system of compensation. There is one oficina where the manager had living with him, besides his wife and three children, two sisters, his wife's sister and child, and his wife's mother. Besides this, he had a large flower and vegetable garden which he irrigated with distilled water.

Labor is all brought into the region. Most of the laborers are Chileans from the south, the rest almost entirely Bolivians and Peruvians. The Chileans are by far the best. Wages at present run about 7 pesos Chilean paper, which is equivalent to about $2 per day at the present rate of exchange. A large proportion of the work is done by contract. There are probably more than 50,000 men employed in the nitrate industry.

All supplies necessary for the industry must be brought in from the outside. These, with the large tonnages shipped away, call for good transportation facilities, and as a result the nitrate fields are well equipped with railroads. These leave the coast from seven different ports, and are obliged to cross the coast range in order to reach the nitrate pampas. They are of all gages, the principal railway at the present time being 30 in. This is the road from Antofagasta to Bolivia, and the system comprises about a 1000 miles of track of this gage. It seems amazing that such a railway can handle anything worth speaking of, but it is over this road that all the equipment for the mines of the Chile Copper Co. at Chuquicamata has been hauled. It is shortly to be widened to 1-m. gage. All the fuel, eatables, the immense amount of mule feed, materials of construction, and supplies of all kinds must be brought to the plants, because the desert produces nothing that is used in the industry, with one exception, *viz.*, the sulphur and niter used for making blasting powder. The sulphur is obtained from some of the extinct volcanoes not far from the nitrate pampas, while the niter is a product of the works. These materials are mixed with soft coal to make "pampa" powder, which serves the purpose admirably.

Cost and Profits of Operation

Costs vary a good deal in different districts and in different plants. The cost of mining depends on the ratio of thickness of overburden to thickness of caliche, and varies from about $0.40 per metric ton as a minimum average, to perhaps $0.75 as the maximum average, except in a few instances. The cost of carriage depends mainly on the manner of occurrence of the caliche. Where the deposits are uniform, thus making it possible to bring the railway close to the working faces, the cost is naturally less than where the caliche must be gathered by carts from widely separated points. It may be as low as $0.20 or as high as $0.50. The cost of treatment varies less than the other items, but here, also, the character of the caliche influences the result. Caliches containing much sulphate salts seem to dissolve with reluctance, and require longer boiling than when the sulphates are low and the chlorides high. Overall treatment cost probably averages about $0.65 per ton, ranging from $0.50 to $0.80. Thus, with general expense, etc., the total cost will range from about $1 to $2 per ton.

The cost of the product will depend on the amount recovered, and hence on the grade. Bertrand estimates the average operating cost of the whole industry at 40d., per quintal ($17.35 per metric ton), the minimum being 28d., the maximum 46d. Sacks, freight, etc., add 10d. to this, export duty 28d. and lighterage, etc., 2d. more, so that the total cost on board ship is about 80d., or 6s. 8d., per Spanish quintal ($35.35 per metric ton). The average selling price, free alongside ship, for the past 10 years has been 7s. 7½d. per quintal ($40.28 per ton). Just at present the price is about 9s. 6d. per quintal.

The industry has been extremely profitable in the past, and is still considerably so. The English companies that publish their accounts show annual dividends ranging from 8 to 20 per cent. on the nominal capital. As with many other companies in the mineral industry, a good many show inadequate returns on account of large promotion profits. For an industry like the nitrate, less than 20 per cent. on the capital invested is insufficient because of the exhaustion of the ground. Technical supervision is generally of a low order, and it is surprising that no more failures result. Of the capital invested in the industry, about one-third is Chilean, one-third English, one-sixth German, and the balance from various countries. The United States is represented by one company only, DuPont, which according to recent reports, is extending its operations.

Composition and Price of the Product

Commercial nitrate contains 95 per cent. or over of sodium nitrate or its equivalent of potassium nitrate. It contains usually 2 or 3 per cent. of K_2O. The potash salt is more soluble than the soda and concentrates

Table 4.—*Price in Europe per Cwt.* (*Cost and Freight*)
(AS. = Ammonium sulphate = 20 per cent. N. N. = Chile nitrate = 15 per cent. N.)

	1911		1912		1913		1914		1915	
	N	AS.	N.	AS.	N.	AS.	N.	AS.	N.	AS.
Jan.	9/6	13/3	10/1	14/4	11/8	14/4	10/5	12/5	10/2	13/
Feb.	9/9	13/10	10/5	14/5	12/	14/2	10/6	12/6	10/10	13/8
March	9/8	14/2	10/10	14/7	12/	13/11	10/7	12/5	11/4	13/6
April	9/9	13/8	11/1	14/11	11/11	13/9	10/4	12/3	12/2	13/5
May	....	13/2	11/1	14/8	11/2	13/1	9/11	11/4	12/10	13/9
June	10/	12/11	11/	14/7	10/8	12/10	9/10	10/6	12/2	14/
July	9/11	....	11/	14/7	10/6	12/10	9/10	10/11	12/2	14/8
Aug.	9/11	14/	11/3	14/4	10/8	....	10/11	10/9	13/	14/7
Sept.	9/11	13/11	11/5	14/5	10/9	13/6	10/7	10/8	13/8	14/6
Oct.	10/1	14/2	11/7	14/1	10/8	13/2	10/	10/8	14/	15/
Nov.	10/1	14/2	11/9	13/10	10/6	13/	9/7	10/10	14/4	15/11
Dec.	10/1	14/2	11/8	14/2	....	....	9/10	11/7	15/	17/

in the mother liquors; the DuPonts take advantage of this fact for the production of a small amount of nitrate high in potash (about 35 per cent. KNO_3). This they do by evaporating the mother liquors, which permits them to wash a little more thoroughly than most operators. This high-potash nitrate they ship to their own works, where it is used in the niter tanks in which the potassium nitrate for black powder is made.

The balance of the commercial salt is sodium chloride, 2 per cent. or less, insoluble matter, and moisture. The Du Ponts are making a very high-grade nitrate (97 per cent.) by charging the finished nitrate into centrifugal driers and throwing in about 10 gal. of water, which dissolves out nearly all the sodium chloride; this grade commands a premium over the commercial grade.

Recovery of Iodine

A byproduct of the nitrate industry that is of considerable importance is iodine. All caliche, apparently without exception, contains this, although the amount varies in different districts. It is believed to exist as calcium iodate, lautarite. In the leaching operation this is converted to sodium iodate, which is very soluble under all conditions, and accumulates in the liquors because of the turning back of the mother liquor into the leaching circuit. It is not produced at all plants, as the market for it, in ordinary times, is not sufficient to absorb all that could be produced. The plants that produce it have an iodine plant as an adjunct, and use the following method:

When the concentration of iodate in the mother liquor reaches a high degree, 10 to 20 per cent., the liquor is delivered into the tanks in the iodine house and treated with a strong solution of acid sodium sulphite. The sodium sulphite is manufactured locally by first deflagrating sodium nitrate with coal and then circulating a strong solution of the resulting crude sodium carbonate, *sal natron,* through towers, into which the fumes of burning sulphur are led. The sulphite reduces the iodate, precipitating iodine, which is allowed to settle and, after decanting, the clear liquid is filtered off and the iodine pressed into cakes in a cheese press. This crude iodine is then sublimed in a coal-fired still, the condensing arrangement being a long string of sewer tile. At one plant in the Aguas Blancas district, where the caliche contains more than the average amount of iodine, 27 tons was produced in 1915. The iodine production of the field is regulated by a trust which apportions to each company having an iodine plant the amount it may produce. In 1905, the last year for which we have figures, the production was 564,000 kg. Doubtless, it is much greater now.

Nitrate Reserves

As to the supply of nitrate for the future, a great deal of speculation has been indulged in and a lot of estimates made; these vary from 20 to

200 years' supply. Actually, it is impossible to form an idea, the question depends on so many unknown facts. It may be that the Government has, or could get, the data for making a reasonably close estimate of caliche. At present, caliche of less than 12 per cent. nitrate is worthless. If, however, the tailings could be reduced to 1 per cent. with little or no additional cost, an immense amount of caliche now worthless would become valuable. Lecturing in 1912, Bertrand stated that the Chilean Nitrate Commission had estimated that there were still, in grounds more or less explored, 215 million tons of nitrate. Allowing for the same rate of increase in consumption for the future as had been shown in the past, this would last about 50 years. The authorities believe, also, that a great deal more exists in grounds as yet unexplored. Personally, we are inclined to doubt this, as we believe, from information received in Chile, that the discovery of any important new fields is improbable. We do think that a great deal more than the amount named will become available through improved methods of treatment and, unless other factors intervene, we should expect that the Chilean nitrate production will continue for a century hence.

These other factors which may alter the situation are the artificial processes of fixing nitrogen. Rapid progress is being made in this art, and there is no telling when nitric acid can be produced synthetically cheaper than it can be extracted from the Chilean deposits. When that is assured, the Chilean nitrate industry will practically cease, and that may occur before the deposits are exhausted.

DISCUSSION

Frederick MacCoy, Raton, N. M. (written discussion*).—In the review of the Chilean nitrate industry presented by Messrs. Rogers and Van Wagenen, the most critical point relating to the future of the industry has been summed up in the last paragraph: "when nitric acid can be produced synthetically cheaper than from the Chilean deposits, the Chilean industry will cease."

A study of the prevailing mining methods and extraction process leads one to suspect that much can be done to reduce the present cost of the finished product; and a reasonable reduction of the cost would make available immense reserves of low-grade *caliche*, the locations of which are fairly well delimited.

In a study of costs, one finds that actual data are very hard to procure. The average operator does not know, with any degree of reliability, his "head assay," what percentage of the caliche is lost in mining, nor what tonnage of caliche he is putting into the *maquina*. One manager

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* Received Feb. 18, 1918.

remarked to me, "We are not concerned in what it costs to treat a ton of caliche, we are interested only in what it costs to produce a quintal of finished nitrate."

Apart from the crude methods of mining, and the inefficient work in extraction, attention is at once drawn to the fact that the 40d., stated as the cost of the nitrate at the plant, has become 80d. by the time it is on board ship. Of this 100 per cent. increase in value, 70 per cent. is for export tax, 25 per cent. is for freight and sacks, and 5 per cent. is for literage at port.

Regarding the export tax, it can be safely stated that when synthetic nitric acid becomes a serious competitor, this tax will be reduced or entirely abolished; for the Chilean Government is not asleep to the possibilities of competition.

Of the item of freight and sacks, approximately half is for sacks. It is not hard to imagine that some method can be developed to ship the nitrate in bulk, or else to produce a cheaper sack than the Indian jute sack at present employed. I understand that one cargo of loose nitrate was shipped to England, but that it became so solidified before arrival that it was necessary to blast it out with dynamite.

J. T SINGEWALD, JR.,* Baltimore, Md.—I have been much interested in the Chilean nitrate deposits, since I had opportunity two years ago to visit a portion of the region in which they occur. Being somewhat familiar with the literature on the Chilean nitrate region, I can say that this is one of the most complete brief accounts of this industry that we have.

In so far as the authors have discussed the genesis of these deposits, they are in essential agreement with the views formed by Dr. Miller and myself at the time of our visit to the region, although differing from the opinions that have been held by others. Previous explanations have been based primarily on assumed conditions under which unusual quantities of nitrate might have been produced, conditions which do not exist today, and there is no particularly good evidence to show that they have ever existed. Our viewpoint has been to consider primarily the factors that actually exist in the region today and have doubtless existed for a long time in the past.

It is true that former conditions in this region may have been a little more favorable for the active generation of nitrates than is the case over most parts of the globe; but, as we all know, nitrates are being formed in nature everywhere. The important factor is the existence of conditions under which those nitrates can accumulate. These favorable conditions exist in the Chilean region to a remarkable degree.

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*Associate Professor of Economic Geology, Johns Hopkins University.

The factors which are particularly to be emphasized are, first, the extreme aridity of the region; this is one of the most arid regions of the globe. A second factor is the relative closeness of ground water to the surface in a region so arid and of such elevation; in one place we saw ground water only 3 ft. below the surface, and from data collected elsewhere the distance is a matter of only tens of feet. A third favorable factor is the porous nature of the material underlying a great part of the Pampa, which induces capillarity and aids evaporation, thereby causing the accumulation of salts. The fourth favorable factor is the constant replenishment of the ground water by circulation from the high Andes on the East. The final factor is the solubility of the nitrate as contrasted with the chloride, which permits efflorescence of the nitrate and separation from the chloride in the surface depressions.

As to the improvements that are being introduced in an attempt to increase the recovery of nitrate, the plant to which the authors refer as having installed filters and screens employed a method similar to that in the Northern field, where that process had been in operation for a short while at the time of our visit. The operators were enthusiastic over the expected improvement in recovery. They screened the caliche over ¼-in. screens and separated thereby 20 per cent. of fines; then in the 80 per cent. of oversize they reduced the nitrate content of the reject to 2.5 per cent. Even if they threw away the 20 per cent. of fines, they increased their total recovery from 60 per cent. to 67.5 per cent.; but they treated the fines by grinding them in a mill, thereby attaining a complete solution, and then filtering the pulp. The *ripio* of the fines carried 4.5 per cent. nitrate, so that the fines yielded an additional recovery of 3.25 per cent., making a total recovery of 16.6 per cent. of the nitrate, as opposed to 12 per cent. under the old system, and increasing the total recovery from 60 per cent. to 83 per cent. The operators were extremely interested in the possibility of working by this system material that had been rejected in the past. Material running under 12 per cent. nitrate was formerly considered worthless, but they are now finding it possible to re-work almost the whole of the nitrate field.

A. H. Rogers.—I understand that the Agua Santa plant has encountered a number of difficulties in filtering. The main object of the grinding was to facilitate filtration rather than solution, filters working best on very fine material. Furthermore, as time went on, they began to get accumulations of liquors that they could not evaporate. A new process is being introduced at the Poposa, which involves evaporation. A number of experiments in evaporation and filtering have given hope that improvement in practice will result. The majority of the operators are very reluctant to undertake new things, because the native experiments have always resulted in failure.

Waldemar Lindgren,* Cambridge, Mass.—It is interesting that every one who has gone to Chile to study the nitrate deposits has come back with a different theory.

My acquaintance with the matter is superficial, but there is a most remarkable dependence of the nitrate on the extent of certain Jurassic intrusives, effusives and tuffs in that region. The coincidence is so clear that there must be some genetic reason behind it. On leaving the nitrate district, you also leave those igneous rocks and come to Jurassic and Cretaceous limestones and sandstones, then granites, and later igneous rocks. That there is such a genetic relationship as is suggested above can hardly be doubted; moreover, in many other countries climatic conditions practically similar to those in Chile prevail without accompanying nitrate deposits.

* Geologist, Massachusetts Institute of Technology.

Genesis of the Sudbury Nickel-copper Ores as Indicated by Recent Explorations*

BY HUGH M. ROBERTS† AND ROBERT DAVIS LONGYEAR,† MINNEAPOLIS, MINN.

(New York Meeting, February, 1918)

CONTENTS

Introduction

During 1916 and 1917, the E. J. Longyear Co. of Minneapolis, Minn., carried out a campaign of exploration for nickel-copper ore in the Sudbury District of Ontario. The work was initiated by W. E. Smith, a resident of Sudbury, who called the attention of W. J. Mead, Chief Geologist

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† Geologist, E. J. Longyear Co.

of the E. J. Longyear Co., to the fact that explorable lands in the Sudbury District were still available. Five diamond drills were employed, and holes were drilled in the townships of Levack, Trill, Denison, Blezard, Garson, Falconbridge and MacLennan. The general map of the District, Fig. 1, shows the distribution of the lands chosen.

As a result of this exploration, a large body of nickel and copper ore has been found in the western part of the Township of Falconbridge. This property lies in the eastern part of the Sudbury District, east of the Garson mine.

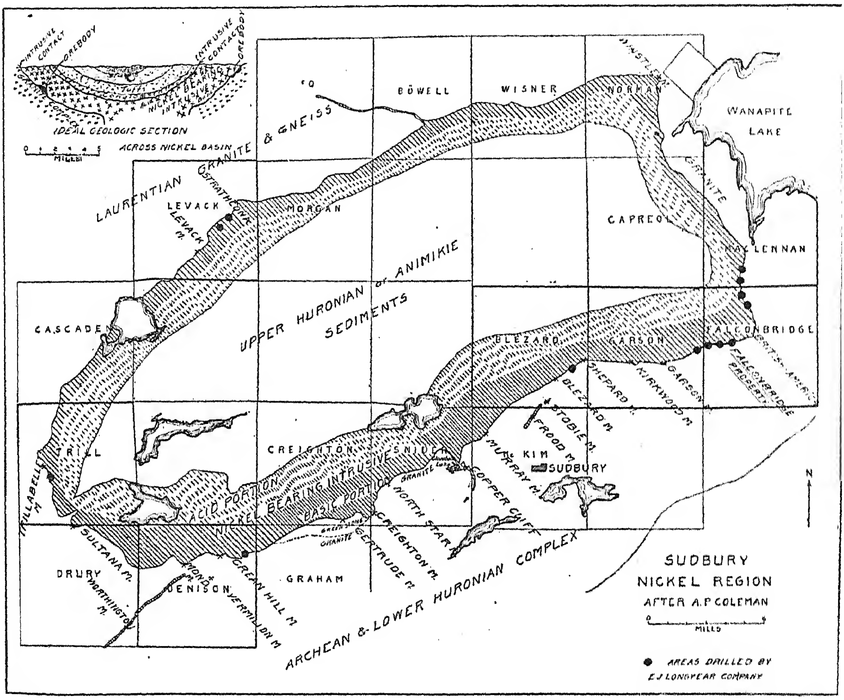

FIG. 1.—SUDBURY NICKEL REGION.

The geological direction of this work necessarily included a careful consideration of the nature and mode of occurrence of the Sudbury ore deposits and of the various existing ideas as to their manner of origin. Since exploratory work is very practical research in the theory of ore deposition, the writers propose in this paper to present the results of this investigation, and in particular to trace the influence of current theories of origin of the ores upon the conduct of the exploration.

The field geology is discussed by H. M. Roberts; the petrography and detailed study of the ore is the work of R. D. Longyear.

We are indebted to C. K. Leith, W. J. Mead, W. H. Emmons and E. C. Harder for suggestions and criticisms.

General Geology

The various places where drilling was to be undertaken were selected on the basis of A. P. Coleman's[1] map and report. This was essentially the latest expression of the thought of Canadian geologists on the Sudbury District, embodying not only Coleman's own more recent work but the previous work of Barlow,[2] Walker,[3] and others of the Canadian Geological Survey and the Ontario Bureau of Mines. Attention was given also to the work by Dickson,[4] Knight[5] and others, concerning the origin of the ore, whose views differed somewhat from those of earlier investigators.

It will not be necessary to enter upon a protracted description of the general geology of the district, as this has been discussed at length in recent geologic literature, but it may be well to outline a few important field relations.

Coleman's map shows a nickel-bearing intrusive, probably of Keweenawan age, which came in as a "laccolithic sheet" or sill. We wish to state our belief in the essential accuracy of this map. The laccolithic sheet is a body some 10,000 ft. (3048 m.) thick and was intruded along an unconformable plane of contact between an older complex of Archean-Huronian rocks, and the younger flat-lying sediments mapped by Coleman as upper Huronian but described later by Collins[6] as Animikie.

During the intrusion and cooling of this mass, the flat-lying sediments of the Animikie were displaced, and deformation of all the rocks in the area took place. The crust of rock covering the internal reservoirs, from which the intrusion came, ultimately settled, so that at present the central portion of the district is folded into a synclinal basin some 40 miles (64 km.) long and 15 miles (24 km.) wide. A great thickness of Animikie sediments has been removed, and also much of the nickel-bearing intrusive itself, bringing the lower portions to view at surface. The distribu-

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[1] A. P. Coleman: The Nickel Industry with Special Reference to the Sudbury Region, Ontario. *Canada Dept. of Mines, Mines Branch, Publication* 170 (1913).

[2] A. E. Barlow: Report on the Origin, Geological Relations, and Composition of the Nickel and Copper Deposits of Sudbury, Ontario. *Canada Geological Survey, Annual Report* (1904), **14**, Part H.

[3] T. L. Walker: Geological and Petrographical Studies of the Sudbury Nickel District. *Quarterly Journal of the Geological Society of London* (Feb., 1897), **53**, 40–66.

[4] C. W. Dickson: The Ore Deposits of Sudbury, Ontario. *Trans.* (1904), **34**, 3–67.

[5] Wm. C. Campbell and C. W. Knight: On the Microstructure of Nickeliferous Pyrrhotites. *Economic Geology* (1907), **2**, 351–366.

[6] W. H. Collins: The Huronian Formations of Timiskaming Region, Canada. *Canada Geological Survey, Museum Bulletin* No. 8 (1914).

tion of the intrusive is oval-shaped, and its outer edge constitutes the outer rim of the basin. The sediments in the interior of the basin have been faulted and continuations of these faulted zones, exterior to the basin, are represented by bodies of norite which were intruded into zones of weakness. These masses constitute forms described by Coleman as "offsets." Typical instances are found at Worthington and Copper Cliff.

Since the time when the magma was hardened into rock, many geologic periods have elapsed. During this interval, the region has been planed down by erosion. In much of the area, all of the rocks are stripped down to the older complex which is itself eroded. The region has since been glaciated.

The nickel-bearing intrusive is composed of two kinds of rock which grade into each other, micropegmatite, a phase of granite in the upper portion, and norite, a species of gabbro, toward the bottom. This gradation has been called in question—notably by Harker.[7] At the very bottom of the intrusive, at its contact with the lower complex as now exposed by erosion, the norite and adjoining rocks contain the iron sulphide, pyrrhotite, with which is associated the nickel-bearing sulphide, pentlandite, and the copper-bearing sulphide, chalcopyrite. Commercial orebodies are found in places where the sulphides form a preponderant part of the rock. Orebodies of this type are described by Coleman as "marginal" deposits. The "offsets," previously mentioned, also carry important orebodies.

We believe, after examining many widely scattered cross-sections, that the intrusive sill is essentially one geologic body, differing in its mineral content from place to place. There are, however, later intrusions of diabase. An intrusion of granite also occurs within the norite near the Murray mine. Toward the interior of the basin, *i.e.*, away from the lower contact of the intrusive, the norite changes its mineralogical characteristics and approaches granite in composition. This is true wherever the rock has been traced away from the contact in the Townships of Levack, Bowell, and Wisner on the north, Trill on the west, and Garson and MacLennan on the east. The more acid rock wherever found is similar in grain, and can always be recognized as a part of the same mass as the basic norite at the edge. In large outcrops of the intrusive, the effect of segregative tendencies in the molten mass may be witnessed; areas, 20 ft. (6 m.) square, or more, may be seen to be dominantly composed of pyroxenes. At a distance of 100 ft., segregations of rock consisting more largely of plagioclase and orthoclase feldspars may be seen. These occurrences are physically continuous and have a continuity of texture and grain. During the course of a single drill hole, for instance, one deep hole drilled in the Township of Levack on the north side of the basin,

[7] A. Harker: Differentiation in Intercrustal Magma Basins. *Journal of Geology* (Sept.-Oct., 1916), **24**, 555–558.

the gradation in the mineralogical composition from basic to acid may be clearly recognized. These facts lead to the conclusion that the intrusive body is essentially one mass, solidifying from a molten magma as a unit. The constant and widely distributed relation between the basic and acid portions of this body leads to the same conclusion.

We agree with Coleman that this mass is a sill, or laccolithic sheet, rather than a dike-like intrusion, for the reason that an inward dip from the contact toward the center has been found at every place where we have drilled—in Levack 45°, in Trill 30°, in Denison 45°, in Falconbridge 70° to 90°, coinciding in this respect with the evidence at most of the mines. The instances of steep and southward dips of the contact on the south limb in Falconbridge Township and at Garson and Crean Hill mines might be accounted for on the basis that the structurally weak sediments and greenstones of those localities yielded under the weight of the intrusive and rolled up before the advancing mass, whereas the more resistant granite, as at Creighton mine, withstood the thrust; hence the relatively flat dips wherever the footwall is composed of massive granite.

The Orebody in Western Falconbridge Township

The orebody, here described, is located in Lots 10, 11 and 12 of the fourth concession of the Township of Falconbridge. As is shown on the accompanying maps, Fig. 1 and Fig. 2, it lies at the eastern end of the southern limb of the synclinal basin, occurring at the outer margin of the norite. The Garson mine of the Mond Nickel Co., 2½ miles to the southwest, is the nearest productive orebody. East of the property, in Lot 8, Con. IV, is a prospect owned by the British-America Nickel Co., where a small tonnage of medium-grade ore has been developed.

The main orebody is shown on the map, Fig. 2, and has a length of 7500 ft. (2286 m.). The exploration was done mainly by diamond drilling. A small exploration shaft was sunk in ore for the purpose of checking the results of the drilling.

A mantle of glacial drift, from 50 to 250 ft. (15 to 76 m.) thick covers most of the rock formation. The few rock outcrops which occur near the norite contact are shown in Fig. 2. In the main, the drift has formed extensive sand plains broken in places by kettles, locally known as pot holes. Cutting diagonally across the western part of the property in a northeasterly and southwesterly direction is a peculiar series of kettles, hills and ridges, which extend northeastward to Wanapitei Lake (Fig. 1).

The general inclination of the bed-rock surface is southeastward toward an old pre-glacial valley now indicated by swamp land, and small lakes. As shown by drilling, there is a rock escarpment along the northwest shore of Boucher Lake over which the glacial material has spilled, forming a steep bank.

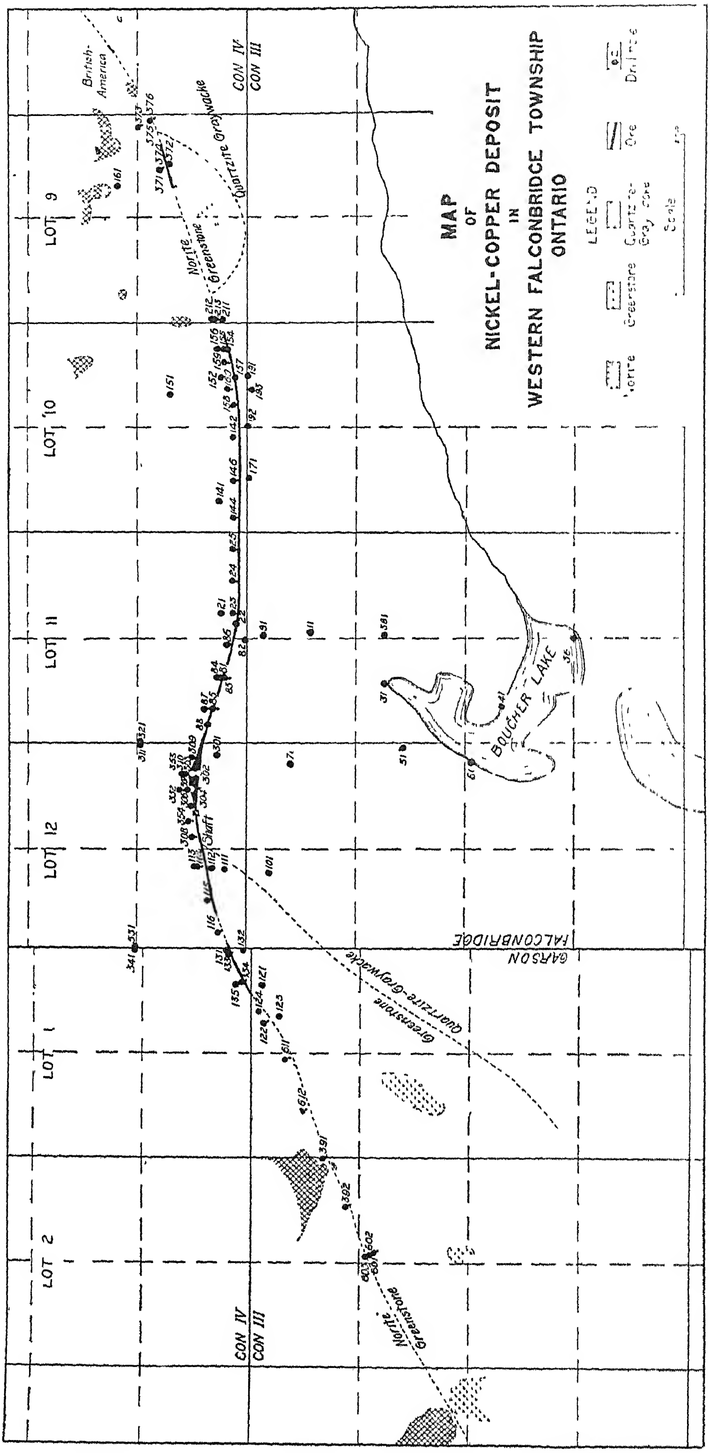

FIG. 2.—MAP OF NICKEL-COPPER DEPOSIT IN WESTERN FALCONBRIDGE TOWNSHIP, ONTARIO.

Quartzite-Graywacke Formation[8]

The quartzite-graywacke formation shown on the map, Fig. 2, is the oldest of the three formations present in the vicinity of the orebody. It is part of a group classified by Coleman as pre-Huronian, and called the Sudbury series. Miller and Knight refer to it as the Timiskaming series. It has a dip of about 90° and strikes about North 80° East.

In this vicinity the formation is composed of about equal proportions of quartz grains and altered ferromagnesian minerals. In some parts the quartz is in excess, and the rock grades toward a true quartzite; while in others the ferromagnesian minerals predominate, giving a more typical graywacke. Some phases of the formation have a marked schistosity approximately parallel to the bedding.

Greenstone

The greenstone is assigned to the Sudbury series by Coleman. It is a fine-grained, altered basic igneous rock composed essentially of amphibole and chlorite probably intrusive into the sediments. In places, it has developed considerable schistosity. It is everywhere cut by intersecting quartz veins varying in size from minute stringers to veins a foot or more in width.

Norite

The term norite is here used to include all phases of the great Sudbury laccolith within the area here discussed. These phases are (1) subordinate amounts of typical unaltered quartz-norite containing hypersthene and quartz, (2) altered norite in which the pyroxenes have been altered to amphibole, making up the greater part of the formation, (3) spotted norite, or altered norite containing blebs of sulphides, occurring as a narrow selvage near the base, (4) minor amounts of granitic material and more acid phases of the norite, found usually near the margin.

Throughout the district, the lower contact of the norite generally has a dip of about 45° toward the center of the basin, but in Falconbridge Township and a few other places, it stands nearly vertical, or even overhangs. The norite thus usually forms the hanging wall of the orebody, and the older rocks the footwall.

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[8] For a general description of the Sudbury rocks see:

A. P. Coleman: The Sudbury Nickel Deposits. *Ontario Bureau of Mines* (1903), **12,** 235–303. The Nickel Industry, with Special Reference to the Sudbury Region, Ontario. *Canada Dept. of Mines, Mines Branch, Publication* 170 (1913).

A. E. Barlow: Report on the Origin, Geological Relations, and Composition of the Nickel and Copper Deposits of Sudbury, Ontario. *Canada Geological Survey, Annual Report* (1904), **14,** Pt. H., also reprint *Bulletin* 96 (1907).

Wherever fresh specimens of norite have been obtained in the Sudbury district, the rock has been found to consist mainly of hypersthene, augite, plagioclase, biotite, and quartz. In most places, the rock has suffered considerable alteration which has changed the pyroxenes to hornblende and uralite. The plagioclase usually has the composition of labradorite.

In the Falconbridge norite, the plagioclase is more acid and varies from andesine (ab_3an_2) to andesine-oligoclase (ab_3an_1). The pyroxenes have disappeared almost entirely, having been replaced by hornblende, uralite, chlorite, and serpentine. A small amount of olivine was noticed in one slide. Quartz occurs as original grains filling the spaces between the other minerals, and also as a fine-grained secondary product of dynamic metamorphism. In hand specimens, the quartz generally has the blue color which is so characteristic of the Sudbury norite. Considerable brown biotite is always present.

A few hundred yards north of the southern contact or base, in Garson and Falconbridge Townships, the norite becomes more acid. Orthoclase feldspars are visible, and there is an increase in the amount of quartz, with a decrease in the amount of ferromagnesian minerals. The quartz is no longer blue. To the north, the rock takes on a more reddish color, and in about 1½ miles passes into micropegmatite containing plumy intergrowths of quartz and feldspar.

Blebs of pyrrhotite and chalcopyrite are visible in the norite along the contact in the vicinity of the ore, but they are seldom found more than a few hundred feet from the contact. The mineral pentlandite, which is associated with the pyrrhotite, can seldom be detected except in a polished section or by etching. The sulphides are later than the silicates, and in many cases replace them. This does not necessarily mean that they were introduced in place later than the intrusion of the norite, but that they *crystallized* later than the silicates. A very common occurrence of the sulphides is in association with biotite, pyroxene, or hornblende, where they usually are found in stringers parallel to the cleavage. This relationship does not seem to occur in the case of the uralite.

Minor amounts of apatite, magnetite, and other accessory constituents are present.

The only rock in this vicinity which has been found to contain hypersthene, is a dark basic rock occurring in the midst of a more acid type about 300 yd. north of the contact, in Lot 2 of Garson Township. It is one of the more basic phases of the norite mass which has suffered less alteration than the other parts.

There is a considerable amount of acid material scattered throughout the base of the norite. In places it is a typical granite; although often it resembles the norite except that it has a larger percentage of quartz and acid feldspars. It has been observed in several of the drill holes, and as irregular patches in outcrops of norite in eastern Garson Township.

The granite material is probably a local segregation phenomenon, and cannot be called a later dike, or included footwall rock. The nearest known granite in the footwall is several miles distant. The contact between the granitic material and norite is seldom sharp, but usually gradational. This gradation is not in the nature of a "reaction rim;" but is very irregular and obscure. One drill hole showed a gradual transition from granite into norite through a distance of 3 ft. (0.9 m.) in which the change took place by a simple decrease in the quantity of alkali feldspars and quartz and an increase in the basic feldspars and ferromagnesian minerals.

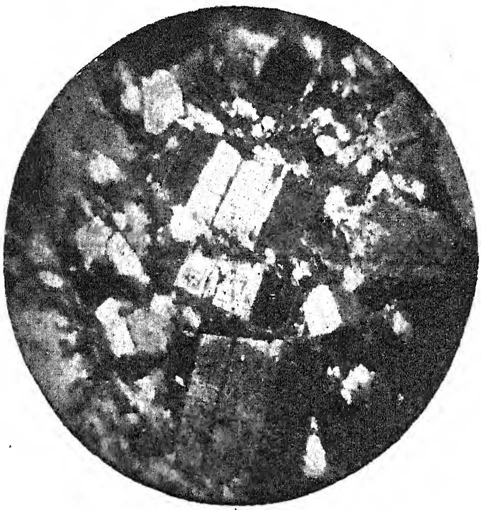

FIG. 3.—PHOTOMICROGRAPH SHOWING FRACTURING IN FELDSPAR CRYSTAL

Metamorphism

All of the rocks show evidence of having suffered metamorphism. This is especially marked in the older footwall rocks, where the sediments have become quartzite, quartz schists, graywacke schists, etc., and where the basic intrusives have been altered to more or less schistose greenstones.

The norite also shows signs of metamorphism, consisting mainly of the alteration of the pyroxene to hornblende, uralite, and chlorite, with a local development of schistosity. The schistosity is more marked near the contact where it is sometimes very difficult to tell whether the rock is norite or footwall. Minute fracturing of the rock-forming minerals can also be observed in places. This is well illustrated by Fig. 3, showing a crystal of feldspar fractured by a number of parallel planes. The fractures are filled with secondary quartz and sericite. This type of fracturing has been described by Howe[9] as occurring at the Frood mine.

[9] Ernest Howe: Petrographical Notes on the Sudbury Nickel Deposits. *Economic Geology* (1914) 9, 505–528.

It would be extremely difficult to attempt to outline a definite historical sequence of the various stages of metamorphism. Tolman and Rogers[10] believe that there was a definite order of mineral formation in the norite, this order being (1) silicates, (2) magmatic alteration of pyroxene to hornblende, (3) ore minerals, (4) hydrothermal alteration products.

From our studies, however, the succession does not appear to be so definite as this. We are not convinced from the evidence presented that the sulphides are later than the hornblende. The possibility is still open that the hornblende is later than the sulphides, for it is simply an alteration product of a previously existing mineral. It is stated that the tremolite is definitely later than the sulphides. No doubt this is to some extent true, since some such alteration is probably in continual operation in all rocks. And yet, in the case of the Falconbridge norite, crystals of hornblende can be seen which grade into a more fibrous uralite (probably similar to the tremolite observed in the slides studied by Tolman and Rogers) and are probably formed at the same time as the uralite.

It seems probable, in the case of the Falconbridge norite, at least, that hornblende was formed *both before and after* the introduction of the ores; and that *most* of the fibrous amphibole has been formed since the ores. At present, we cannot determine a more accurate sequence.

The Orebody

As indicated in Fig. 2, the orebody occurs at the contact of the norite and footwall in a continuous band extending from the southwest corner of Lot 12, Con. IV, to the southeast corner of Lot 10, Con. IV, in the Township of Falconbridge. This is a total length of 7500 ft. (2286 m.), which is longer than any other known orebody in the district. This length has not been completely explored throughout, but it is a reasonable assumption that the ore is continuous over this length. Beyond the ends of this orebody are smaller outlying deposits (see Fig. 2), making the total length of the mineralized zone some 11,200 ft. (3413.76). The thickness varies from a minimum of 10 ft. (3 m.) to a maximum of about 120 ft. (36 m.). The greatest depth at which the orebody has been cut by a drill hole is 1020 ft. (310.9 m.) below the surface of the ground. It probably extends to a much greater depth.

This orebody is a typical example of the so-called marginal deposit of the Sudbury district. In general, the ore is at the contact of the norite hanging-wall and the underlying quartzite or greenstone, as is shown in Fig. 4. In some cases, however, the ore is several feet away from the contact, and within the quartzite or greenstone. This type is illustrated by Fig. 5. The ore generally dips steeply to the north. In two places,

[10] C. F. Tolman, Jr. and A. F. Rogers: A Study of the Magmatic Sulphide Ore. *Leland Stanford, Junior, University Publication,* University Series (1916).

overhanging dips to the south have been observed. In some places the walls have a very irregular shape.

The ores can be classified in three types: (1) norite partly impregnated with sulphides, (2) footwall (usually quartzite on this property) partly impregnated with sulphides, and (3) massive sulphides containing small particles of rock. The last type grades into the other two.

The sulphides in the norite usually take the form of blebs scattered uniformly throughout the rock. The sulphides in the footwall rocks may be blebs, but are more often in the form of irregular veinlets. Often the

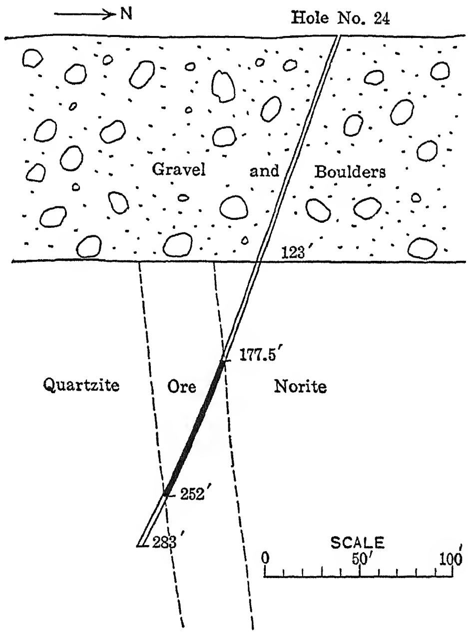

FIG. 4.—CROSS-SECTION OF DRILL HOLE No. 24.

rock associated with the ore is so schistose that its original nature is uncertain.

In the massive ore, it is rare to find less than 5 to 10 per cent. of rock particles present. These particles may consist of quartz, norite, quartzite, greenstone, or an indeterminate schist. They may be rounded, subangular, or angular, and generally suggest replacement by the sulphides.

Mineralogy

The sulphide minerals comprising the ore are, in order of abundance, pyrrhotite ($Fe_{11}S_{12}$), pentlandite ($FeNiS_2$),[11] and chalcopyrite (CuFeS).

[11] This formula corresponds approximately with analyses made of the pure mineral pentlandite of the Sudbury district, although pentlandite from other localities sometimes shows less nickel and more iron. C. W. Dickson: The Ore Deposits of Sudbury. *Trans.* (1904), **34**, 21.

The proportions of minerals present are shown graphically in Fig. 6. The first column represents the composition of a sample of typical mineralized or "spotted" norite. Each of the other columns represents a composite sample of all ore in a drill hole between the foot and hanging walls. The relative amount of minerals present was calculated from the analyses given in Table 1. It was assumed that all of the nickel occurs in the form of pentlandite. Cobalt and arsenic were neglected as being too insignificant in amount to affect the results.

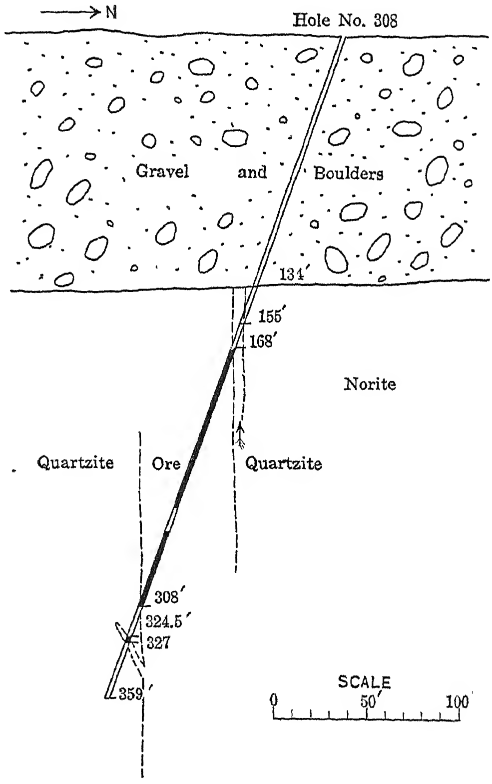

FIG. 5.—CROSS-SECTION OF DRILL HOLE No. 308.

It will be seen that a very large proportion of the lode material is rock. It is customary in Sudbury mining practice to remove part of this rock by hand picking. The rest could be easily removed by flotation or some other mechanical process; however, a certain amount of siliceous gangue is necessary as a flux in the furnace for slagging the iron. The rock gangue consists of quartz, or any of the country rocks or their altered equivalents. Calcite is rarely found.

The amount of chalcopyrite present seems to bear little relationship to the amount of rock, being as abundant in the rocky ores as in the richer

ores. Pentlandite, on the other hand, increases as the amount of rock decreases, and bears a fairly constant ratio to the amount of pyrrhotite present. Fig. 7, showing the analysis curves for copper, nickel, and combined copper and nickel, illustrates the same features. The "copper curve" has practically no slope from left to right (rocky to less rocky ores), while the "nickel curve" rises toward the right. A striking feature

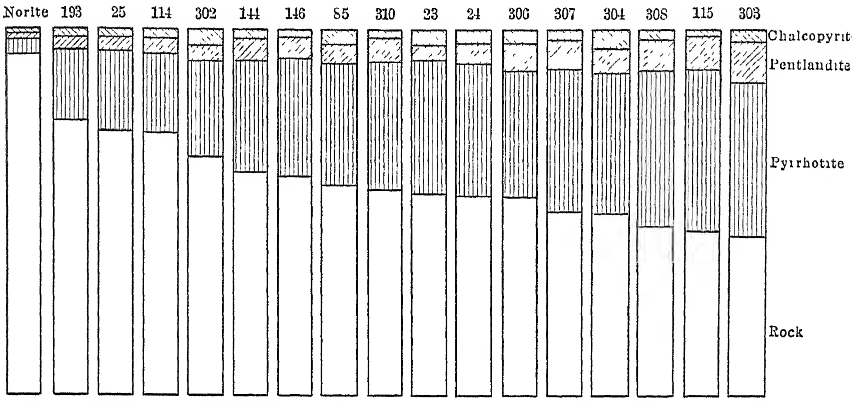

FIG. 6.—GRAPHIC REPRESENTATION OF THE RELATIVE AMOUNTS OF SULPHIDES AND ROCK GANGUE IN SEVERAL DRILL HOLES.

of this diagram is the complementary nature of the copper and nickel curves, maximums on the one curve being opposite minimums on the other, showing that where the copper is more abundant the nickel is less abundant.

Fig. 8 shows the ores of Fig. 6, recalculated so as to represent what would be the composition of the sulphides alone if the rock were entirely

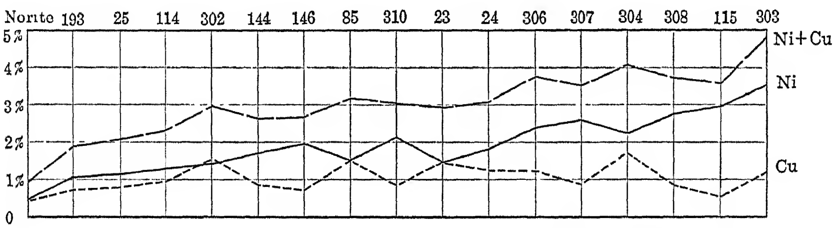

FIG. 7.—CURVES SHOWING THE PER CENT. OF NICKEL AND COPPER IN THE ORE OF SEVERAL DRILL HOLES.

removed. The remarkable uniformity in the composition of the ore is at once apparent. The chalcopyrite is the most variable member; the pentlandite is somewhat more constant, while the pyrrhotite, except in the first column (hanging wall), is invariably around 75 and 80 per cent. The bearing of this feature upon the problem of the genesis of the ores will be discussed later.

Fig. 9 shows graphically the metallic content of the pure sulphide samples represented by Fig. 8. This indicates that pure sulphide concentrates of the ores, if made, would have practically a uniform

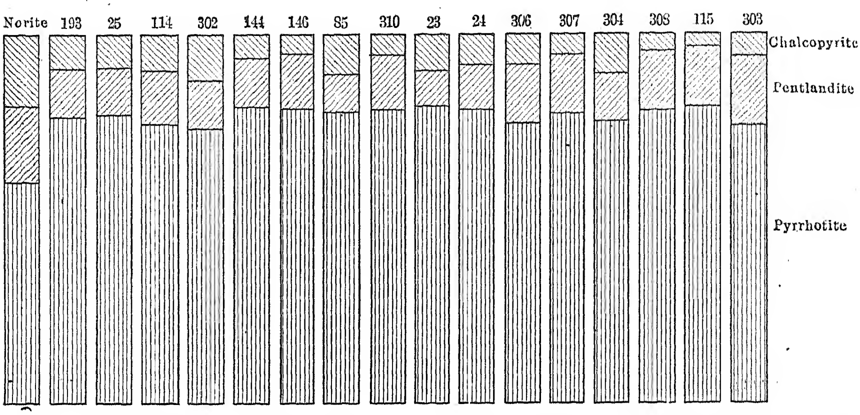

FIG. 8.—GRAPHIC REPRESENTATION OF RELATIVE AMOUNTS OF SULPHIDES IN THE ORE OF SEVERAL DRILL HOLES.

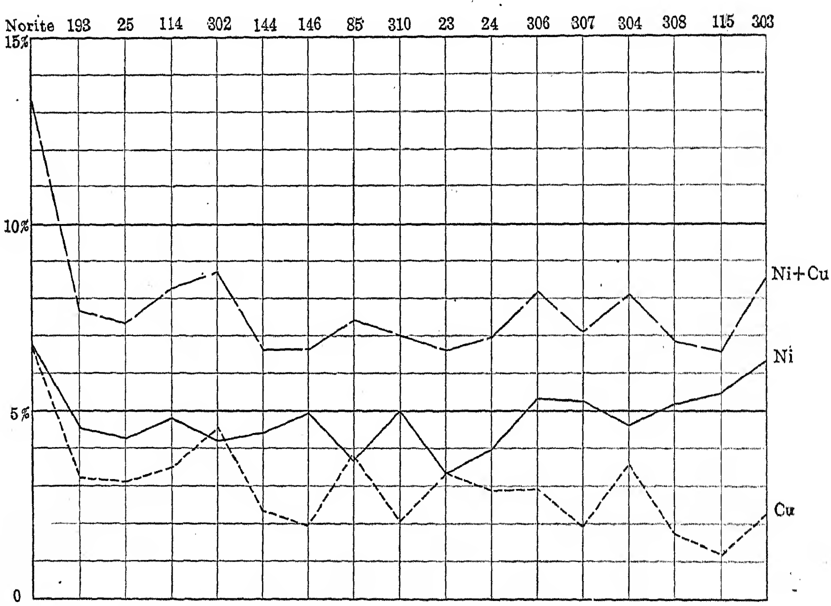

FIG. 9.—CURVES SHOWING WHAT WOULD BE THE PER CENT. OF NICKEL AND COPPER IN THE ORE OF SEVERAL DRILL HOLES IF ALL OF THE ROCK GANGUE WERE REMOVED.

content of 7 to 8 per cent. combined metals. In the hanging wall, however (first column), where the processes of mineralization would naturally be more erratic, the sulphide concentrates would have a com-

bined metallic content of 13.42 per cent. This suggests the possibility of a commercial exploitation of the "spotted norite" in the not far distant future, when the present ore reserves have been exhausted.

The order of crystallization of the sulphides is (1) pyrrhotite, (2) pentlandite, (3) chalcopyrite. A photomicrograph of a polished section of the ore is shown in Fig. 10. The pentlandite (white) occurs as irregular masses and veinlets within the pyrrhotite (light gray). The dark material is the silicate gangue. A patch of chalcopyrite (dark gray) can be seen between two masses of gangue. The ratio of pentlandite to pyrrhotite is generally somewhat less than is indicated in this photograph. The sulphides are later than the silicates.

The fact that the chalcopyrite is relatively more abundant with respect to the other sulphides in the rocky ores than in the richer ores

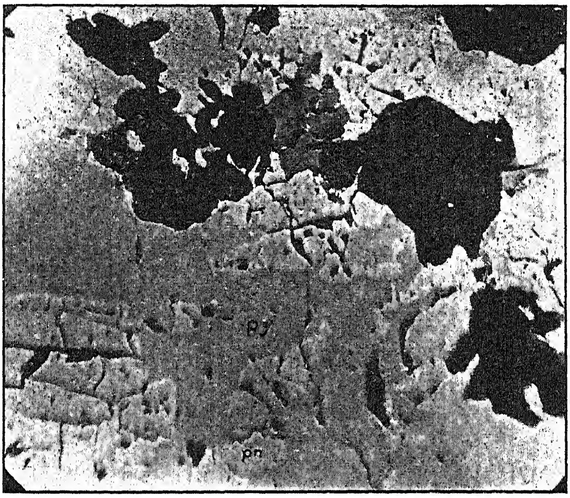

FIG. 10.—PHOTOMICROGRAPH OF A POLISHED SECTION OF THE ORE. *Py*, Pyrrhotite; *Pn*, Pentlandite; *ch*, Chalcopyrite.

can be explained, possibly, as follows: Although all of the sulphides were deposited from the same melt—or, more properly, solution—yet they were deposited in a regular order. The pentlandite was deposited later than the pyrrhotite, but followed it so closely that they are very intimately associated with each other and occur in a nearly constant ratio. The deposition of the chalcopyrite, on the other hand, seems to have been retarded somewhat, for its occurrence is very irregular. The solid masses of pyrrhotite and pentlandite did not allow the chalcopyrite to penetrate them to any extent, so it was forced to lodge in the channels formed between the pyrrhotite and rock particles. Also, being more soluble, it was able to migrate further into the rock. Thus the solid masses of pyrrhotite contain less copper than the rocky ores.

Magnetite is present in the ore in small amounts, but its period of formation has not been determined. Pyrite has been observed in some of the core but the amount is negligible. It appears to be later than the other sulphides. In one place, a narrow band of galena was found cutting the mineralized norite. It is clearly a later introduction and not directly connected in origin with the orebody. Aside from these, no other sulphides have been detected, although a detailed study would undoubtedly disclose the presence of some of the rare nickel minerals, such as polydimite, gersdorffite, etc.

Grade of Ore

During the course of the drilling, 90 to 95 per cent. of the core was recovered. When in ore, this core was split longitudinally by means

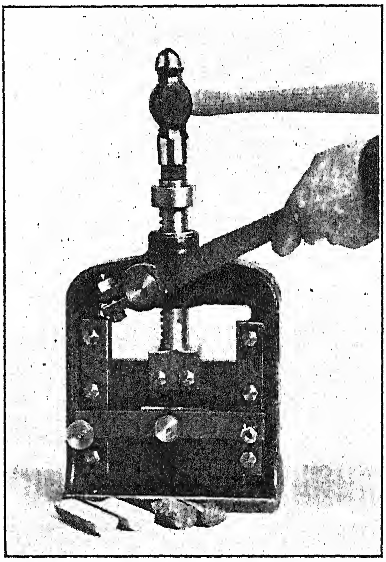

FIG. 11.—"CORE-SPLITTER" DEVISED FOR SPLITTING DRILL CORE BEFORE ANALYZING IN ORDER TO PRESERVE A COMPLETE SAMPLE OF THE ORE WITHOUT INTERFERING WITH THE ACCURACY OF THE ANALYSIS.

of a "core-splitter" devised for the work, Fig. 11. One half was kept on file as a record of the physical characteristics of the ore, and the other half was ground for analysis. In uniform ore, intervals of 5 ft. (1.5 m.) were analyzed. In mixed ore and rock the division points were chosen according to the character of the material; but in no case was a smaller interval than 6 in. (152.4 mm.) analyzed, nor a greater interval than 5 ft. About 600 samples were thus analyzed. The determinations made were nickel, copper, iron, sulphur, and silica, with occasional tests for gold, silver, and platinum. The analyses were made by the Minnesota Testing Laboratories, Inc., of Duluth, Minn.

The content of the ore varies from 2 to 5 per cent. in combined metals. The nickel content is fairly uniform in the massive ore, usually running about 2.5 to 4.3 per cent. The copper content is very irregular and ranges from 0 to 5 per cent. with occasional higher values.

Composite samples of the ore in 16 of the drill holes were prepared and sent to Ledoux & Co. of New York for analysis. The results are shown in Table 1.

TABLE 1.—*Analyses of Composite Ore Samples from Diamond Drill Holes*

Hole Number	23	24	25	85	114	115	144	146
Silica (per cent.)	29.84	27.85	31.44	35.09	31 20	19 55	34.22	27.92
Sulphur (per cent.)	16.23	17.08	10.63	16.08	10.69	20.87	14.87	15.26
Iron (per cent.)	27.90	29 65	24.80	24.95	23.00	35.50	26.60	27.65
Arsenic (per cent.)	0.02	0.039	0.07	0.08	Trace	Trace	0.09	0.03
Copper (per cent.)	1.45	1.27	0.87	1.59	0.98	0.61	0.90	0.74
Nickel (per cent.)	1.45	1.79	1.19	1.55	1 35	2.97	1.72	1.96
Copper-nickel (per cent.)	2.90	3.06	2.06	3 14	2.33	3.58	2.62	2.70
Cobalt (per cent.)	Trace	0.14	0.01	0.01	0 02	0.01	0.01	0.01
Silver (oz. per ton)	0.20	1.00	0.20	0 30	0.15	0.04	0.19	0.20
Gold (oz. per ton)	0 012	0.21	0.014	0.002	0.007	0.004	0.007	0.005
Platinum metals (oz. per ton)	0 004	0.02	0.006	0.004	0.005	0 004	0.003	0.009

Hole Number	193	302	303	304	306	307	308	310
Silica (per cent.)	41.00	35.08	20.37	25.43	26.25	27.03	23.36	29.68
Sulphur (per cent.)	9.55	12.41	21.49	18.98	17.23	18.85	20.40	16.21
Iron (per cent.)	20.25	22.70	35.40	32.10	29.75	31.40	33.95	27.80
Arsenic (per cent.)	0.06	0.08	0.125	0.03	0.06	0.09	0.08	0.21
Copper (per cent.)	0.80	1.56	1.20	1.79	1.31	0.91	0.90	0.88
Nickel (per cent.)	1.14	1.43	2.57	2.22	2.41	2 60	2.75	2.15
Copper-nickel (per cent.)	1.94	2.99	3.77	4.01	3.72	3.51	3.65	3.03
Cobalt (per cent.)	Trace	0.02	0.25	0.25	0.02	0.02	0.02	0 03
Silver (oz. per ton)	0.30	0.16	Trace	0.22	0.10	0.20	0.13	0.18
Gold (oz. per ton)	0.003	0.013	0.03	0 008	0.023	0.007	0.003	0.007
Platinum metals (oz. per ton)	0.003	0.007	0.01	0.006	0.013	0.004	0.004	0.007

These analyses are a fairly accurate representation of the average grade of the mixed ore and rock, within the commercial walls of the ore-body. In actual mining operations, some of the rock would be sorted from this ore and thus raise the grade.

GENESIS OF THE ORES

The genesis of the Sudbury ores has been a subject of keen debate for a number of years. The data brought to light by this exploration,

which has developed one of the large orebodies of the district, lends a new emphasis to some phases of the problem, and it will be of interest to discuss in a general way the facts concerning the deposits and the various conclusions which may be drawn from them.

The apparently conflicting theories of origin are all based upon certain facts. These *facts*, as distinguished from *inferences*, are enumerated below:

1. The ore generally occurs at or near the margin of the main norite mass. Where the ore is not near the main laccolith ("offset deposits"), norite is always found associated with the ore, or in close proximity to it.
2. The ore minerals are later than the rock-forming minerals of the norite.
3. The ores penetrate and replace the foot-wall rocks to some extent.
4. The rock associated with the ore appears to be more or less brecciated.
5. The walls of the commercial orebody are usually sharply defined, mineralogically.
6. The norite wall is always spotted with sulphides. The foot wall is sometimes spotted, and sometimes barren.
7. The mineralogical content of the "marginal deposits" is singularly uniform, with a fairly constant ratio between the amount of pentlandite and pyrrhotite, although with a slightly more variable quantity of chalcopyrite. The content of the "offset deposits" is not so uniform as that of the marginal deposits.
8. The usual minerals accompanying typical hydrothermal deposits are scarce or lacking, and in many places the norite associated with the ore is unaltered.
9. The norite laccolith has been differentiated into an upper stratum of acid material and a lower stratum of basic material. Within the basic material are minor amounts of acid rocks.

Summary of Various Hypotheses

On the basis of these facts, a number of hypotheses concerning the genesis of the Sudbury ores have been offered. In general, they fall into two classes: those which postulate a magmatic origin, and those which postulate that the ores are the result of a later introduction by hydrothermal solutions.

The following is a brief outline of the more important theories concerning the origin of the ores:

Magmatic Segregation by Crystallization of Sulphides.—The older school, headed by Barlow,[12] believed that the ores were formed by a

[12] A. E. Barlow: Report on the Origin, Geological Relations and Composition of the Nickel Copper Deposits of the Sudbury Mining District, Ontario. *Canada Geological Survey, Annual Report* (1904), **14**, Part H; also reprint, *Bulletin* 96 (1907).

process of magmatic separation in which the sulphides were the earliest minerals to crystallize and were concentrated at the edge of the norite. Barlow believed that the concentration took place according to Soret's principle by which a substance crystallizing from a solution or melt is concentrated in the cooler part of the solution. Others place more emphasis on gravity and believe that the concentration was due to the sinking of the sulphide crystals.

The principal arguments advanced in support of this hypothesis are: (1) the ore always occurs at the margin of norite, (2) the sulphides are natural constituents of the normal norite.

The main objection to this theory is that microscopic investigation shows that the sulphides are not the first minerals to crystallize but the very latest, and, therefore, could not become concentrated in this manner.

Gravitational Segregation of Molten Sulphides at the Base of the Magma. —Coleman[13] believes in the gravitational separation of the sulphides, not as crystals, but as a melt. In support of his theory, he cites the following: (1) The ore is universally associated with norite; (2) where fracturing has occurred along the contact the molten norite and ore have penetrated the footwall, forming *offset deposits;* (4) the norite associated with the ore does not show the typical hydrothermal alteration minerals; (5) the distribution of the ore around the contact corresponds roughly with the volume of the norite lying above the ore.

The objection to this theory, as well as to that of Barlow, lies in the fact that there is evidence of considerable solutional activity in the orebodies, since, to a large extent, they are found replacing the footwall rocks. Coleman ascribes this to rearrangement by subsequent solutions; but it seems improbable that there could be such a large amount of rearrangement without the formation of some typical secondary minerals, *i.e., secondary* in a mineralogical sense.

It is true that in some places the ores are localized in a depression in the floor of the norite, or "bay-out." In Falconbridge Township, however, the richest and largest portion of the orebody occurs on a "bay-in" (Fig. 2), a condition that would be improbable if gravity were the sole controlling factor.

Intrusion of Molten Sulphides after the Consolidation of the Norite.— Howe[14] and Bateman[15] support the hypothesis that the separation took place in a deep-seated reservoir and that the ores were introduced as a

[13] A. P. Coleman: The Nickel Industry, with Special Reference to the Sudbury Region, Ontario. *Canada Dept. of Mines, Mines Branch, Publication* 170 (1913).

A. P. Coleman: Magmas and Sulphide Ores. *Economic Geology* (August, 1917), **12**, 427–434.

[14] E. Howe: Petrographical Notes on the Sudbury Nickel Deposits. *Economic Geology* (1914), **9**, 505–522.

[15] A. M. Bateman: Magmatic Ore Deposits, Sudbury, Ont. *Economic Geology* (August, 1917), **12**, 391–426.

separate intrusion of molten sulphides. Their evidence lies in the brecciated nature of the contact and the fact that the ore seems to occur as a cement filling the interstices between the fragments.

As mentioned above, the ore deposits have to some extent the characteristics of deposits from solution and are not clear-cut intrusions of molten material. Moreover, the roughly constant proportions of ore and norite indicate that the segregation must have taken place within the laccolithic chamber now occupied by the norite mass. This relationship will be developed more fully in the course of this paper.

Deposition by Hydrothermal Solutions.—Other observers, as Knight[16] and Dickson,[17] see no immediate relation between the norite and the occurrence of the ore, and observing that the ore occurs mingled with the footwall granite, quartzite or greenstone, as the case may be, as well as with the norite itself, come to the conclusion that the ore is formed by hydrothermal solutions which have permeated the contact zone between the intrusive and the footwall.

The ore is considered to be a cement, replacing the fine-grained matrix of "crush conglomerates" and "crush breccias." The improbability of gravitational segregation is suggested by pointing out the dike-like nature of the norite mass in several localities. The solutions which formed the ore presumably came from depth at a period later than the hardening of the norite to rock, and had no immediate relationship with the adjacent norite, but perhaps were derived from the same source that supplied the norite magma.

Knight cites geological conditions in the vicinity of the Creighton mine to support the theory of ore deposition by hydrothermal solutions coming subsequently to the hardening of the norite and after the intrusion of a supposedly younger granite, thereby inferring that the process of ore deposition did not immediately accompany the intrusion and solidification of the norite. If his inferences have truth, it is not clear why the contact of greenstone (see Fig. 1) and the supposedly younger granite has not somewhere yielded sulphides—for instance, in the vicinity south of the neighboring Gertrude mine. The point of this question is that no sulphides occur along the contact of the granite except where it meets norite. The greenstone might be expected to have lent itself quite as readily to fissuring and replacement as the norite. A traverse of this supposedly younger granite mass indicates to us that it is in reality older than the norite.

The writers have examined considerable portions of the contact

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16 C. W. Knight: Origin of the Sudbury Nickel-Copper Deposits. *Engineering and Mining Journal* (May 6, 1916), **101**, 811–812. Geological Relations of the Sudbury Nickel Ores. *Engineering and Mining Journal* (Sept. 23, 1916), **102**, 554–555. *Report of Royal Ontario Nickel Commission* (1917), 105–211.

17 C. W. Dickson: The Ore Deposits of Sudbury, Ontario. *Trans.* (1904), **34**, 3–67.

between the norite and the granite in the area from the Creighton mine to the Copper Cliff offset, and nowhere see evidence to the effect that granite intrudes norite, except near Clarabelle Lake along the Copper Cliff offset, an occurrence that may well be a local later intrusive. It is possible that some of the supposed granite dikes observed by Knight, along the contact, are of granitic material segregated within the norite mass, similar to that occurring in Garson and Falconbridge Townships, which has been described in this paper.

The granite mass of the area between the Creighton mine and Copper Cliff mine is not a homogeneous body, but contains infolded greenstones and schists. The types of granite vary from coarsely porphyritic to fine-grained; the various phases are intrusive one into the other; and the area bears all the characteristics of an old Archean-Lower Huronian complex. Even assuming that the granite mass is one homogeneous body, the relation of the norite to the granite at Copper Cliff No. 2 mine is a difficult matter to explain. The space relations shown by a detailed areal map of this vicinity indicate that the norite is the intrusive body rather than the granite, since a tongue of norite cuts across the granite.[18]

Wherever the norite contact has been viewed in the Townships of Denison, Graham, and Snider, the textures and mineralogical constituents differ at the immediate contact from the characteristics shown within the mass. These variations are not the result of dynamic changes, but are a strict function of the distance from the contact, and point to the fact that the norite rather than the granite has the change in grain at the contact due to differential segregation. This leads to the conclusion that the granite is older. The granite complex has suffered more regional deformation than the norite, as a walk along the Algoma-Eastern Railway, between Crean Hill mine and the Gertrude mine, will make apparent. This points to the older age of the granites. Deductions proceeding from a few obscure contacts cannot be permitted to outweigh the large field relations. It is our opinion that the suggested intrusive relation of the granite into the norite is not proved. This is borne out by other observers.[19] Viewing the subject, as a whole, evidence based on the age relationship of this granite mass cannot be considered as having great weight in arriving at a hypothesis which accounts for the origin of the ores.

The hypothesis that preëxisting cavities in the form of contact cooling fissures or brecciation zones were filled by the work of solutions does not seem tenable. It is difficult to account for the presence of

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[18] A. P. Coleman: *Nickel Industry.* Geological Map of Copper Cliff Offset.

[19] A. P. Coleman: Geological Relations of the Sudbury Nickel Ores. *Engineering and Mining Journal* (July 8, 1916), **102,** 104–105.

E. Howe: *Loc. cit.*, 521.

C. H. Hitchcock: Personal Communication.

extensive brecciated zones, 50 to 150 ft. (15 to 45 m.) thick, on the bottom contact of a mass of solidifying magma, 10,000 ft. (3048 m.) thick, with an over-capping of the whole Animikie series having an additional thickness of 10,000 ft. The prevalent inward dips of the norite mass and the relations of the overlying Animikie sediments argue strongly that the present contacts which are now brought to the surface by erosion were deeply buried at the time they were formed. Fissured zones of the magnitude necessary to provide for the orebodies could not exist under a capping of miles of rock.

The apparent brecciation and presence of vein-like stringers of sulphides can be accounted for as phenomena accompanying the solidification of both the norite and the sulphides. On the instant that openings began to form as a result of readjustment which accompanied the solidification of the norite, they were filled with the still molten sulphide. The intrusion and solidification of so great a mass of magma is not to be thought of as a simple, brief process; on the contrary, a long time interval was no doubt involved, accompanied with the interplay of enormous pressures. Perhaps the nearest visible analogy to conditions prevailing at the base of the intrusive are those at the edge of a slow-moving glacier, where ice flows under pressure, entraining fragments from the surface over which it moves, melting and congealing, changing continually from solid to liquid and back again to solid; fractures are no sooner produced than healed again.

The fact that nickel-bearing ores are nowhere found at any considerable distance from bodies of norite, shows that their introduction into the footwall was essentially a part of an intrusion phenomenon occurring near or within the zone of rock flowage, and that the process was one of penetration by digestion or "magmatic stoping," rather than by the replacing of breccias.

Much hydrothermal activity did occur in open-faulted zones, which cut the rocks above the cooling nickel-bearing sill, as the zinc blende and pyrite occurrences in the interior of the basin indicate, but no nickel deposits are found there. It is not necessary to assume the existence of fissures to account for the intrusive nature of the Worthington and Copper Cliff norite masses. It is necessary only to predicate the preëxistence of zones of weakness which, at higher levels in the Animikie rocks, manifest themselves as faults.

The region where the offsets are now found was once covered with nickel-bearing intrusive. The evidence for this is the heavy erosion which must have been necessary to produce the present distribution of the Animikie sediments and norite. Small plasters and remnants of norite are found exposed in many places exterior to the basin proper. The material composing the offsets is norite identical in composition with the norite of the basic margin. The rocky nature of the ores in the

offsets and the so-called "solution boulders" are evidence of more fluidity and circulation during the cooling than in the marginal deposits. This can be accounted for on the basis that the "offsets" were the deep-seated zones of weakness corresponding with the faults above and were places of constant readjustment during the long cooling process.

Schistose phases have been developed in the norite, as may be seen in many places along the contact, as in the Townships of Denison, Blezard, and Falconbridge. Large areas of schists are also to be found among the acid phases of the norite in the interior away from the contact. These schists were developed after the rock had hardened from the melt, for the reason that they may be traced directly into normal crystalline norite within short intervals. The schists occur in large volume, measurable in hundreds of cubic yards. The norite which has thus been rendered schistose must have been in a region of great pressure at the time when the schists were developed. There could have been no large openings filled with brecciated norite or footwall in the immediate vicinity, certainly none of sufficient size to account for the orebodies. The ores themselves exhibit the effect of pressure. (See an able paper by Howe.[20]) It is reasonable to suppose that the dynamic changes in the ores and the surrounding rocks occurred at the same time.

A conclusion may be drawn from these facts and inferences: At some time subsequent to the formation of the ores, while the whole mass was yet in the zone where deformation occurs by plastic yielding with the development of micas among the ferromagnesian minerals and incipient fracture in the quartz and feldspars, both the ores and the adjacent rocks were subjected to pressure. All of which argues the previous existence of the ores in this zone before deformation occurred and before the region had been lifted out of that zone, either relatively by erosion or by actual uplift. The deformation now evidenced by the schist and ore may have occurred during the initial stages of that uplift. It might be maintained that the ores had been formed in a brecciated zone and subsequently deeply buried, to permit the phenomenon exhibited, but it is not a reasonable or likely explanation and is not in accord with the usual geological history of the district.

It is difficult to see how it would be possible to arrive at just conclusions concerning the value of any tract of land on the nickel-bearing intrusive if one proceeded upon the theory that later hydrothermal solutions coming from below attacked the norite and footwall along planes of weakness. It would seem that during the period through which this district has been open for prospecting, someone would have found orebodies along the many shattered zones within the mass of the norite itself, remote from its bottom contact. The regular and uniform occur-

[20] E. Howe: Petrographical Notes on the Sudbury Nickel Deposits. *Economic Geology* (1914), **9**, 505–522.

rences of the ore at the immediate base do not point to the action of vagrant hot solutions. It might be asked, if hot solutions subsequent to the cooling of the norite have in reality been the source of the ore, why orebodies should not have been developed in greenstones and graywackes of the complex distant from the occurrences of norite, as in the silver veins of the Cobalt district where silver is often found at considerable distances from the diabase with which the mineralizing solutions are thought to have been genetically related.

Magmatic Segregation by Extraction from Crystallizing Norite.—Tolman and Rogers[21] recently proposed a very plausible theory to account for the origin of the ores. They hold that as the process of crystallization of the norite proceeded, the sulphides were extracted by the mineralizers present, and finally deposited, as a last stage in the consolidation of the magma, along the basal contact.

This process is a separation of the ores from the magma practically in place and in that sense is *magmatic segregation.* On the other hand, the mineralizers present caused replacements in both the footwall rocks and in the cooling norite above, and hence gave the orebodies the appearance of having been deposited from *solution.*

Tolman and Rogers have formulated from detailed microscopic study a succession for the minerals in the norite as follows: (1) silicates, (2) magmatic alteration of pyroxene to hornblende, (3) magnetite, (4) pyrrhotite, (5) pentlandite, (6) chalcopyrite, (7) hydrothermal alteration of silicates to tremolite, chlorite, etc. On the basis of this succession, they have determined the age of the ores to be later than the magmatic hornblende and earlier than any hydrothermal minerals, and, therefore, place it definitely at the close of the magmatic period.

The essential difference between this theory and Coleman's theory is that less stress is laid upon the part played by gravity, and that the segregated sulphides are considered to have more the character of a solution than a melt.

Although we are not willing to accept without qualification all of the conclusions which they draw from the microscopic evidence, yet their theory appeals to us as being the most plausible explanation yet offered to account for the genesis of the Sudbury ores. Especially convincing is the accumulative evidence gathered from world-wide sources that there is a distinct type of sulphide ore deposits the origin of which can be traced to magmatic segregation.

The Relation Between the Exploration and Theories of Origin

A choice between the various hypotheses previously discussed is a matter of great importance to the explorer who is endeavoring to con-

[21] C. F. Tolman, Jr., and A. F. Rogers: A Study of the Magmatic Sulphide Ores. *Leland Stanford, Junior, University Publications.* University Series (1916).

duct a rational search for ore. Such a choice of views is important not only in reference to the value of any one parcel of land along the contact but also in regard to the handling of any one drill hole. There is one condition common to all of these theories: The orebodies that have now been found do occur along the contact of norite with some other adjacent rock. This is true not only of the sill as a whole, but of the offsets as well; although in many of the offsets sulphides occur throughout norite dikes. Thus any lands along the norite contact might be expected to carry ore. The explorer must answer this question: Which lands among those along the norite contact warrant the greatest expenditure for the purpose of finding ore? Every consideration that will help in solving this difficult problem is of great importance.

When this exploration was started, the later publications by Tolman and Rogers[22] and by Knight[23] were not available, but a study was made of existing publications.

In the early stages of the work, drilling was carried on, simultaneously, in the various townships indicated on the map, Fig. 1. As far as the immediate local facts in the field might show, all of these localities presented about equal opportunities for finding a body of ore. It may be of interest to record briefly the results of the exploration in the various townships, touching particularly upon the factors which determined the course of the work.

In the Township of Levack, on the north limb of the basin, three holes were drilled between the Strathcona mine and the Levack mine. The relative position of these mines led to the belief that ore might be found along the norite contact between them. Only one hole was drilled to the contact. This hole is typical of many of the holes drilled and is therefore described. It started in a uniform phase of the norite and continued in this for a depth of 500 ft. (152 m.) the proportion of pyroxene and basic minerals increased as the hole deepened, and many anhedra of pyrrhotite appeared. Between the depths of 500 and 600 ft., portions of the core were composed largely of basic minerals; other portions were plagioclase feldspar. These segregations gave to the rock the appearance of having a gneissoid structure.[24] Within this material were found a few

[22] C. F. Tolman, Jr. and A. F. Rogers: *Op. cit.*

[23] C. W. Knight: Geology of Sudbury Area. *Report of the Royal Ontario Nickel Commission* (1917), 105–211.

[24] In the Report of the Royal Ontario Nickel Commission for 1917, Knight describes the Levack mine, and maps this gneissoid segregation as granite gneiss, thus classing it with the basement complex, differing therein from the views of the present writers who would regard it as a segregated phase of the norite. Similar segregation gneisses are common at the base of the nickel-bearing intrusive elsewhere, as in the Townships of Trill and Denison, and are unquestionably portions of the intrusive. Banding of this type is common in connection with other intrusive bodies. For instance, many such occurrences are found within the Duluth gabbro, a large sill of Keeweenawan age, in northern Minnesota, according to F. F. Grout of the Minn. State Geological Survey (personal communication).

occurrences of pyrrhotite and chalcopyrite, each attaining perhaps to as great a volume as 1 cu. in. (16 cu. cm.). At 600 ft., the drill encountered the coarse-grained, flesh-colored granite of the footwall, decidedly different from any of the rock above.

Drills working in the Township of Trill in the western part of the district and in the Townships of Denison and Blezard, encountered much the same types of norite with segregation phenomena near the contact as described in connection with the drill holes in Levack. No commercial quantities of sulphides were found, which, of course, does not necessarily mean that such bodies may not be found. Meanwhile, drills were at work in the Townships of Falconbridge and MacLennan in the eastern part of the district. Typical norite was encountered there also, after penetrating the glacial drift. The norite at the contact in Falconbridge differs in no degree from the norite encountered elsewhere, except that outcrops to the north indicate that the basic portion of the intrusive sill is wider than in the other localities where drilling was done. In attacking this region, it was planned to refrain from deep, costly rock drilling until the position of the contact had been definitely determined by "scout" holes which would merely penetrate ledge for a few feet. These were put down through the drift for the purpose of marking out the position of the contact; thus the deeper holes had a definite basis for the choosing of their location. In the early stages of the work, one hole near the contact was drilled to a depth of 600 ft. (182 m.) in norite but did not encounter foot wall rocks, thereby indicating that the norite contact had a steep dip.

At this time, lands in the Townships of Bowell, Wisner, and Graham were also available for exploration, but it was decided not to drill them. The drills were withdrawn from Levack, Trill, Denison, and Blezard and the exploration was concentrated upon the Townships of Falconbridge and MacLennan where the contact was largely concealed by glacial covering, but where, so far as known, the norite had the same mineralogical characteristics at the immediate base as the norite found during the course of the other explorations. In addition to the drilling, and while it was in progress, studies of many portions of the norite contact were made in the field wherever it was exposed to view.

Volume Relations of Norite and Sulphides

As a result of this work and of a consideration of all the large field relationships as shown on the maps of the Sudbury District, the following general condition had been becoming apparent: The quantity of sulphides which may be expected to occur at the contact of the nickel-bearing intrusive is roughly proportional to the volume of the adjacent norite.[25]

[25] Coleman, among all the writers on the Sudbury District, has been foremost in recognizing this condition.

The surface expanse of the nickel-bearing intrusive and its thickness as shown by the dip at the contact both go to show what the volume of the tributary nickel-bearing intrusive may be.

The one great expanse of nickel-bearing intrusive in the district which, so far as known, did not have a commensurate body of sulphides accompanying it, lay in the eastern part of the district in the Township of Falconbridge. An inspection of Fig. 1 will show that the nickel-bearing intrusive in this vicinity has a much greater width than in the Townships of Wisner, Bowell, and Levack on the north, or Trill on the west. The norite has a great width in the Townships of Denison and Blezard, but the accompanying orebodies had already been discovered; *i.e.*, Creân Hill mine and Blezard mine. Hence, it was decided to concentrate on the contact in the Township of Falconbridge, even though it was covered by 150 to 200 ft. (45 to 60 m.) of gravel and boulders.

In this connection, it may be noted that in regions where the offsets are highly mineralized, the adjacent basic margin does not yield orebodies; *i.e.*, in the region of the Worthington and Mond mines, the marginal contact of the main intrusive is quite generally exposed and no orebodies have been found along it. In the region of the Frood mine, which is found on an offset, the margin proper does not yield orebodies, indicating that the metallic content which was a portion of the magma in these vicinities, when found in one place does not occur in quantity in another portion of the "horizontal cross-section" or plan now exposed by the erosion surface. This relationship is, of course, rough, discernible only in broad outlines, but is sound evidence for the conduct of exploration, safer than speculation arising from more detailed features of any one hand specimen or any one orebody. General evidence of this kind is more likely to be a safe guide for the projection of work in unknown areas, since the reasoning proceeds from the nature of the intrusive process as a whole, not from any one phase which may be dominated by local conditions.

While the discovery of ore in Falconbridge Township as a result of assuming a relation between the volume of norite and the volume of sulphides may be only a coincidence, nevertheless, the outcome is a strong indication that some such close relationship actually does exist.

Intimate Association of Norite and Sulphides

Another factor which has been emphasized by this exploration is the intimate association of the ore with the norite. In Falconbridge Township, it usually occurs at the immediate contact, the hanging-wall being entirely norite and the footwall entirely quartzite (Fig. 4). Where the ore is actually within the quartzite (or greenstone) it is never more than 20 or 25 ft. (6 or 7 m.) from the base of the norite. Moreover, the drill

core often shows that the gangue within the ore is norite, while the rock above and below may be quartzite or greenstone.

This is well illustrated in Hole 308, a cross-section of which is shown in Fig. 5. Below the main body of ore, the drill passed through 16½ ft. (5 m.) of barren quartzite only to enter again a 2½ ft. (0.76 m.) stringer of rich ore containing small included particles of *norite.* The association of the norite with this last shoot of ore is extremely suggestive, and points strongly to the fact that they both came from the same source and were closely contemporaneous.

Granitic Material

The constant presence of the granitic material associated with ore at the contact, as described in detail previously, is indicative of the final breaking up of the melt at the contact into two poles; one, the very basic sulphides, and the other, the acid phase or granite. The differentiation of the main laccolithic sheet on a broad scale into norite at the base and micropegmatite at the top, is a larger manifestation of this segregative tendency.

In view of this tendency of the magma, which appears to be especially noticeable near the contact, it is most natural to conceive that the ores are simply one phase of the differentiation. The present knowledge of the physics or, as it might be termed, the physiology of a molten magma, is too speculative to warrant further analysis into the machinery of this splitting up. It is sufficient to note that the broad field relations force this conclusion—the sulphides and the accompanying rock phenomena developed essentially *in situ.*

Uniform Content

The uniform content of the ores and its bearing on their genesis has been previously emphasized by Barlow and Coleman. This feature is illustrated by Fig. 6, 7, 8 and 9, which show a remarkable similarity in content of the samples taken from separate drill holes as previously noted. This relationship holds in a general way for all of the *marginal deposits* in the Sudbury District. It is difficult to believe that solutions coming from any great distance would be capable of producing so many singularly uniform deposits over such a large area. The fact that the *offset deposits* are not of this uniform character and are known to show more resemblance to typical hydrothermal deposits is of special significance in this connection. The regularity in content seems to be a function of the proximity to the main norite mass, and ties up the source of the ores more definitely to the immediate norite laccolith.

Sulphides in Walls

The character of the walls of the Sudbury orebodies has a distinct bearing upon the question of the origin. The contact of the *commercial*

orebody in any one spot is usually sharp and well defined. There is no mineralogical gradation, as sometimes described, although an actual "mining gradation" may be found which is due to blocks of included rock near the wall, or to veinlets of ore penetrating the wall. This fact is usually pointed to as evidence of hydrothermal origin. The character of the wall rock outside of this commercial zone, however, varies, depending on whether it is *norite,* or one of the *basement rocks.*

The norite wall is always spotted with blebs of sulphides. The spotted norite passes by insensible gradations into barren norite containing practically no sulphides.

Where the wall rock is granite, greenstone, or some other rock, it is not always spotted with sulphides, being sometimes entirely free from the presence of ore minerals within a few inches of the ore. Of 35 drill holes, which penetrated quartzite contacts in Falconbridge Township, only eight of them showed any noticeable sulphide mineralization in the quartzite, beyond the commercial wall.

During the course of drilling and field study, it has been found that ore occurrences in the footwall are not functions of the character of the footwall rocks but that masses of sulphides replace quartzite, graywacke, granite, and greenstone, irrespective of their widely different chemical and mineralogical compositions. In the study of ore deposits caused by replacement through the agency of hydrothermal solutions, if any one fact is brought out with emphasis, it is that hydrothermal replacements depend directly upon the character of the rock replaced. There can be no question that replacement of the footwall rocks occurs in connection with every orebody in the district, but there is nothing irrational in assuming that a molten magma and the hydrothermal solutions immediately emanating from it might not be just as efficacious in this regard as the hot solutions coming from any supposed distant magmatic reservoir. The assumption that the immediately adjacent melt was the active replacing agent would give a rational explanation for the widely different rocks which are attacked. That is, the molten sulphides and the accompanying solutions were injected into the positions where they did their work, because they were a part of the solidifying intrusive mass of norite in that immediate vicinity, and not because the nature of the various rocks replaced was essentially favorable to the replacement.

Absence of Typical Hydrothermal Minerals

There has undoubtedly been alteration in the footwall and in blocks of norite enclosed with ore. However, wide field examination fails to show the extensive alteration that usually accompanies large orebodies of exclusively hydrothermal origin, as described, for instance, in connec-

tion with the Bisbee copper deposits[26] or the lead-silver deposits of the Tintic district of Utah.[27]

There is no special alteration of the footwall immediately accompanying the ore, but the footwall, in nearly all cases, shows only the original alteration common to any of the older rocks in the district. The mass of the norite itself adjacent to the orebodies gives no evidence of alteration, as distinguished from the norite mass in any other portion of the intrusive body.

The absence of the usual hydrothermal altération products in the norite suggests that the norite must have had sufficient temperature to be virtually in equilibrium with the solutions carrying the sulphides, permitting replacement without alteration.

Summary

By way of summary, a possible succession of events which produced the Sudbury ores is outlined below:

A laccolithic mass of molten rock was intruded along a plane of unconformity beneath the Animikie sediments. Through some process of differentiation[28] the nature of which is uncertain, this mass separated and consolidated into two distinct but intergrading types, micropegmatite and norite. The sulphides were carried downward with the norite. As the norite consolidated, these sulphides remained in solution and were concentrated in association with an acid component of the magma. This segregation or "extract" made its way to the base of the norite under the influence of complex chemical and physical forces. At the very last stage in the consolidation of the norite, the sulphides were precipitated from the "extract" along the contact, and at the same time, the acid component solidified into granite. The presence of water, sulphur, and possibly other mineralizers in the magma, gave this extract somewhat the character of a *solution*, enabling it to replace the wall rock to some extent. But it was still so intimately related to the magma that it was unable to carry the sulphides any great distance into the footwall, unless also accompanied by the molten norite.

With this point of view, it is merely a question of emphasis whether these ores are considered to be of magmatic or hydrothermal origin. The point we have tried to make clear is that the dominant factor controlling the deposition of the Sudbury ores is *magmatic segregation in situ*. Hot solutions may have been active, but only served to influence the local character and position of the ores.

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[26] Y. S. Bonillas, J. B. Tenney, and Leon Feuchère: Geology of the Warren Mining District. *Trans.* (1916), **55**, 284–355.

[27] Guy W. Crane: Geology of the Ore Deposits of the Tintic Mining District. *Trans.* (1916), **54**, 342–355.

[28] Bowen would ascribe this differentiation to the sinking of the pyroxene crystals. N. L. Bowen: Later Stages of the Evolution of the Igneous Rocks. *Journal of Geology* (Nov.–Dec., 1915), **23**, *Supplement*, 1–91.

DISCUSSION

George F. Kunz, New York, N. Y. (written discussion*).—We have been informed that the nickeliferous ores of Sudbury could furnish more palladium than the whole of the present world supply, together with a large amount of platinum. As the quantity of ore melted in Sudbury in 1916 totaled 1,521,689 tons, giving 80,010 tons of matte, and as the average of 3 years, up to 1915, are stated to show an average of 0.10 oz. of platinum and 0.15 oz. of palladium per ton of matte, this would indicate the presence of 12,000 oz. of palladium and 8000 oz. of platinum in the ore mined in 1916.[1]

Interest in the platinum situation is now more intense than it has ever been, and the great importance of this metal for many special uses is being increasingly appreciated. For munition manufacture, for chemical apparatus, in dentistry, and for jewelry, it has been and continues to be in great demand in spite of the phenomenal rise in its value. It is true that this has necessarily led to a search for substitutes, especially for dentistry and chemical uses, but while some of these have been found to answer the needs fairly well, for many other purposes platinum is still employed in spite of its great cost. As to the jewelry industry, the most public-spirited efforts have been made to restrict its use, and its employment in the manufacture of watchcases, purses, bracelets, and catches has been abandoned, gold being used in its place.[2]

The prime cause of the present shortage is, of course, the elimination of the Russian supply which, in normal times, constituted probably the larger part of the world's production. This makes an intensive search for new sources of supply imperative; and the present ruling price of the metal should powerfully stimulate this search as it renders profitable the treatment of material containing so very small a proportion of platinum or of the platinum metals that, before, there would have been a loss instead of a gain in recovering them.

Mining companies everywhere should be urged to bear this in mind, and the results of all analyses should be carefully studied with this end in view, as an amount of platinum heretofore regarded as but slightly greater than a trace may make the residuum of the ore, after the content of gold, silver, or nickel has been extracted, profitably treatable for platinum.

In this connection there should be a careful search of the black sands of the Pacific coast, always bearing in mind that whereas this might have been objectless with platinum selling at from $10 to $15 an ounce, satisfactory returns may be had with the price at from $100 to $115 an

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* Received Feb. 16, 1918.

[1] Recovery of the Metals of the Platinum Group. *Report of the Royal Ontario Nickel Commission*, No. 1839 (1917), Chap. X, 481, 484. Toronto.

[2] George F. Kunz: Platinum for the Year 1916. *Mineral Industry* (1917), **25**.

ounce. Great care should be taken when washing the black sand from gold placer mines and dredges, as it is always possible that platinum, osmiridium, and other metals of the platinum group may be present.

It is gratifying to learn that the deposits in the United States of Colombia, which rank second to those of Russia, are being developed with greater energy than formerly, but still the work there is more or less irregularly carried on, and the slightly increased output goes but a small way toward making good the loss of the Russian supply, which in any case already showed signs of approaching diminution or exhaustion.[3]

All these facts clearly emphasize the necessity for a consistent, intelligent and active search for platinum in all ores in which it exists, whether in larger or smaller amounts, even down to an amount that in times past has been looked upon as negligible; and our metallurgists and chemists can aid in a work of great national and industrial value during these trying times by aiding to stimulate the search for new sources of these valuable precious metals of the platinum group.

It is most important that special attention be given to detecting the presence of platinum in the residues from the sulphide of iron and nickel, pyrrhotite; from the sulphide of copper, chalcopyrite; from pyrite; from the ores of nickel occurring in peridotite rock, or in serpentine resulting from the decomposition of the same peridotite; and in any similar rocks containing chromite, for chromite is an associated mineral with platinum throughout the entire Ural region.

Frank F. Grout, Minneapolis, Minn. (written discussion*).—It must be very satisfying to those who, like the authors, have conducted explorations on the basis of a theory, to have that theory supported by the discovery of an immense orebody. Of course, the discovery of ore does not prove the theory; but it at least puts a heavy burden of proof on those who "see no immediate relation between the norite and the occurrence of the ore."

It may be well to note that the authors' conclusions do not seem to conflict with those recently arrived at by M. A. Dresser.[4] There may be some question whether the fractured feldspars and other dynamic effects illustrated by the authors, and ascribed to metamorphism, are the exact equivalent of the fractures noted by Dresser. Dresser had evidence that some fractures developed before magma solidification was complete; it would not be unreasonable, however, to expect a later dynamic metamorphism in addition. It may even be possible to find a mineral or structural difference in the two developments. For example, the frac-

* Received Feb. 23, 1918.

[3] George F. Kunz: Platinum, with Especial Reference to Latin America. *Bulletin of the Pan American Union* (November, 1917), 606–626.

[4] *Economic Geology* (1917), **12**, 563.

turing that occurred early is shown by Dresser to be accompanied by a corrosion and plastic deformation of the plagioclase crystals; the cracks are mostly filled with a graphic intergrowth of quartz and feldspar, with some sulphides and hornblende. On the other hand, the development of a quartz-sericite filling in some cracks, as mentioned by the authors, may be a distinctly later thing.

Nevertheless, while there may have been a late metamorphism, the authors apparently are wholly in accord with Dresser in the belief that there was some dynamic action at a magmatic stage, for they speak (p. 48) of the brecciation "accompanying the solidification of both the norite and the sulphides." It seems that the occurrence of an earth movement at just this critical moment when the magma was half solid, and the sulphides mostly liquid, will overcome many of the difficulties in the theories of the origin of the ores. And Dresser has abundant petrographic evidence that the movement was nicely timed at just that moment. Many fractures are filled with both micropegmatite and sulphides which crystallized together.

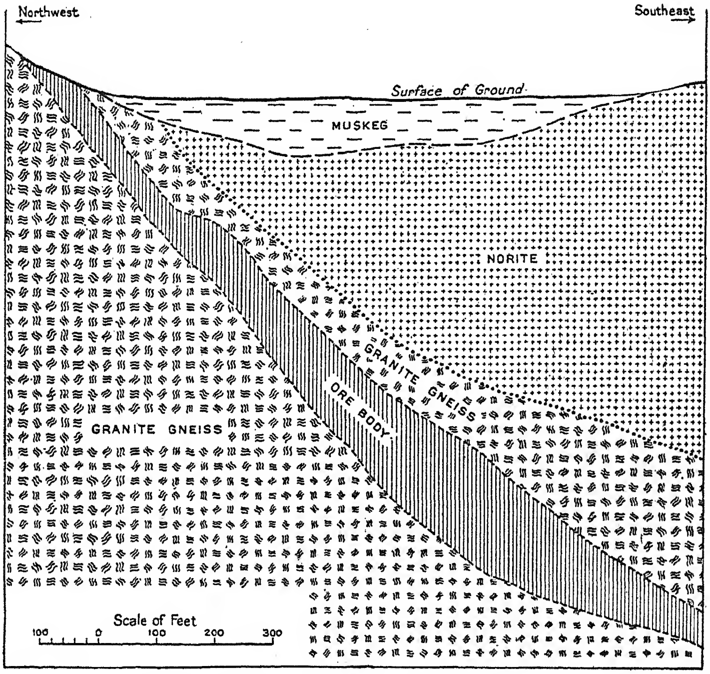
Petrographers will be interested also to note that the differentiation of the rock did not result in a single sequence, from basic bottom to acid top; nor in such a series modified by a chilled border. There is, rather, a double or triple series; there was a separation of one or more immiscible fractions, at the same time that crystallization and settling were producing some variety in the norite. The banded structure, which the authors mention, indicates a still further complexity in the process, for the alternation of such rocks as they find in the norite probably develops only when the magma is in convection circulation during crystallization. This variety of processes is far from the simple evolution (due to crystal settling) sometimes assumed for igneous rocks.

W. G. Miller,* Toronto, Ont.—The authors are to be congratulated on giving us this description of the recently discovered orebody. I may not quite agree with Mr. Roberts that magmatic origin had very much to do with the discovery of the ore, because that section of the country in which it has been found has attracted the attention of people at various times. For instance, a number of years ago Mr. Edison had parties investigating the area; but of course this company with which Mr. Roberts is associated is very important and well equipped for doing this kind of work, and we are very glad that they have made this important discovery in Ontario. I might say, moreover, that I do not think many of the mining men who have developed properties at Sudbury have paid much attention to igneous or aqueous theories, or recognized them at all. They have gone along and discovered ore, and the prospectors outlined the occurrence of those ores before geologists mapped the district. So

* Provincial Geologist, Ontario Bureau of Mines, Canada.

that the discovery of most of those deposits did not depend very much on theories of origin. I suppose few of the early prospectors ever heard the name igneous or magmatic.

Nearly everybody at present has come to agree that the nickel deposits, such as the Worthington, which lie at some distance from the so-called norite sill, are of aqueous or later origin. It therefore seems to me that we should hesitate, in view of those deposits on which we all agree, to be very dogmatic respecting the origin of other deposits on which we do not agree.



CROSS-SECTION OF THE LEVACK MINE, ONTARIO.

Mr. Roberts refers to the relation of the granite at the Creighton mine to the norite. Mr. Knight maintains that the granite is younger than the norite; if Messrs. Roberts and Mr. Longyear do not agree with him on that contact, probably they will agree as to the contact at the Murray mine, where, in the lower levels of the mine, the granite forms the footwall of the orebody.

Of course, we should not draw too hard and fast lines between magmatic and aqueous. I think most of us agree that most ore is ultimately connected with intrusions. For instance, in many of our gold areas, in Ontario especially, we look on the gold veins as being end products of granite intrusions. Then at Cobalt and surrounding areas we have a

diabase sill, and we all agree that the cobalt, nickel, silver, and arsenic ore are genetically connected with that sill, but nobody would call them magmatic ores, *i.e.*, direct segregations.

The origin of Sudbury ores has formerly been presented much more simply than it has been by the latest writers. For instance, certain earlier descriptions were to the effect that the ores separated out of magma very much as a precipitate settles in a beaker. I do not think there is so much difference between the opinions of Mr. Roberts and Mr. Knight as there might appear to be.

The authors have not quoted Mr. Knight quite correctly in regard to his theory of origin, where they say: "Other observers, as Knight and Dickson, see no immediate relation between the ore and the norite." What Knight really said was:[5] "Inasmuch as the orebodies are more closely associated with the norite than with any other rock, it would appear that the heated waters given off by that immense mass of igneous material, or from its deeper seated molten reservoir of rock, may have played an important part in the formation of the ores." And again: "It may be pointed out that all observers agree there is some connection between the origin of the ore and of the norite."

That the theory of origin, on which the authors have based their diamond-drill prospecting, may have led them astray, in one case at least, is seen from the following quotation from their paper. "In the Township of Levack, on the north limb of the basin, three holes were drilled between the Strathcona mine and the Levack mine (of the Mond Nickel Company). The relative position of these mines led to the belief that ore might be found along the norite contact between them. Only one hole was drilled to the contact." Not finding ore at the contact the authors ceased drilling in this part of the area. If they had drilled down below the contact into the granite they might have discovered an orebody of similar character to that of the great Levack mine, a cross-section of which is shown in the accompanying illustration, taken from Mr. Knight's description in the Report of the Royal Ontario Nickel Commission, page 165.

Curiously enough, although there has been so much written on the theory of origin of these rocks and ores, it is only within the last year and a half that any estimate has been made of the ore reserves proved in the Sudbury area.

The deposit which Messrs. Longyear and Roberts have discovered is, I think, one of the poorest in many ways to prove anything about the igneous or magmatic segregation theory, because, as they say, it has a vertical contact, and does not "bay-out" from the contact, but inward.

The authors refer to the absence of secondary minerals. In some

[5] *Report of the Royal Ontario Nickel Commission*, pp. 130 and 133.

mines there are large quantities of minerals that are secondary, as, for instance, quartz. There have been 35,000 tons of quartz mined at the Garson mine and there are very many tons left there.

On page 29, Bell's work ought to have been mentioned, because he was really the man who first outlined the basin. On page 36, the order of crystallization of various minerals is given; that crystallization was first worked out by Campbell and Knight; not by Tolman and Rogers, as stated. Then, of course, this theory of magmatic segregation is an old theory. It was not originated by Barlow, Coleman, and other workers in Canada, but had been suggested by men in various parts of the world before they came on the scene.

The authors say "The walls of the commercial orebody are usually sharply defined, mineralogically." Mr. Knight. has made a similar statement, but other writers have given a different description. When the authors say that "The ore minerals are later than the rock-forming minerals of the norite" they agree rather with Dickson and Knight than with writers who have upheld the magmatic segregation hypothesis.

Mr. Knight's views, as I understand them, of the relations between the Sudbury norite and the nickel-copper ores may be put briefly as follows: (1) Intrusion of norite, which passes at times into more acid facies. (2) Intrusion of rocks of the composition of granite. (3) Deposition of the nickel-copper ores. This is the same order as has been observed in connection with the Nipissing diabase and the nickel-cobalt-silver ores of Cobalt and the surrounding region. The Nipissing diabase has been compared with the Sudbury norite.[6]

Alan M. Bateman, New Haven, Conn.—I think this paper is an extremely interesting contribution to our knowledge of Sudbury deposits, and of magmatic ores in general; it also gives additional information about a part of the Sudbury laccolith, or the rim of the intrusive, that has always been buried by soil. The authors' opinion, as I gather it, is that these ores are formed by a process of magmatic segregation *in situ*, but by just what process it has taken place is not clear from the paper.

I agree with them that the accumulation of recent evidence regarding those deposits prevents the acceptance of a magmatic segregation as postulated by Barlow and Coleman. There seems to be a large accumulation of evidence against their process of magmatic differentiation, and it seems clear also, from evidence that has been produced in recent papers, that the ore minerals or the sulphides, are later than the rock minerals.

If the ore did not originate by magmatic segregation *in situ*, it remains, then, to be shown the time and process of accumulation of

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[6] W. G. Miller and C. W. Knight: Sudbury, Cobalt and Porcupine Geology. *Engineering and Mining Journal* (1913), **95**, 1129–1132, and *Report Royal Ontario Nickel Commission*, 121.

sulphides. Any evidence that would throw light on the time of the ore formation with respect to the norite intrusion would be of unquestionable value in ascertaining the origin of those deposits. I think this is all the more important, inasmuch as segregation *in situ* could not have occurred if the segregation had been separated from the norite intrusion by some other geological process. Messrs. Roberts and Longyear, however, rather lightly dismiss the age relations of the granite and the bearing it may have on ore deposition; they state that it is of little practical importance anyway.

I would disagree with this statement, because it seems to me that the age of the granite in question is a very important factor in determining the origin of those ore deposits; for if, as Knight claims, the granite intrudes norite, and ore in turn intrudes granite, it is clear that the ore is later than the norite, and between the period of ore formation and norite solidification there was a granite intrusion, so that the ore cannot be a segregation of norite. Hence, the age of the granite is an extremely important factor in this discussion.

I have not had an opportunity to examine the recent disclosures of the field relationships of this granite and norite, but the detailed evidence and photographs by Dr. Miller and Dr. Knight[7] leave the reader in little doubt that the granite is intrusive into the norite; at least the granite that they are discussing, though not all of the Sudbury granite.

Messrs. Roberts and Longyear suggest that perhaps Dr. Knight has mistaken inclusions of granite in norite for dikes of granite. I hardly think that such an error is probable on the part of Dr. Knight, who has had such abundant opportunity for access to all of the mines, and for whose geological ability we all have such great respect.

On reading this paper rather critically, I find opinions as to the age of the granite, but no demonstrating evidence proving its age, nor proving that the granite does not intrude the norite, as they suggest. Hence there is more or less conflict of opinion regarding field relations, and, until that point is settled, we cannot go very far toward explaining these very puzzling ore deposits, nor can we accept the conclusions presented in this paper. Undoubtedly the authors have more data regarding the granite intrusion than they were able to present in their brief paper, and if they could contribute more detailed evidence it would help to elucidate this difficult problem.

On reading the excellent collection of geological field relations presented by the authors, I can detect some evidence which might be construed to favor the idea, originally suggested by Ernest Howe,[8] of a

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[7] Nickel Deposits of the World. Ontario Legislature, Toronto, 1917. Chapters on Sudbury, by C. W. Knight.

[8] Petrographic Notes on the Sudbury District. *Economic Geology* (1914), **11**, 503.

differentiation in the magmatic reservoir below and subsequent intrusion of a magma highly charged with sulphides. This would explain the intimate relation between norite and sulphides. The authors object to this theory on the ground that the deposits show to some extent the effects of action by solution, and also because there is a constant proportion between the ores and the norite rock. I do not think that these two reasons are sufficient to dismiss Howe's hypothesis, for the hydrothermal characteristics may have been imposed later upon ores previously formed by magmatic intrusion. One interesting feature of ore deposition, as shown in so many mining camps, is that the formation of ore does not occur as a single limited phenomenon, but is rather a geologic event, extending over considerable time, and often embracing several stages. As hot springs usually follow vulcanism, so may some hydrothermal deposition follow magmatic ores, and impose its effects upon them.[9]

Again the constant proportion between norite and ore is no more an argument in favor of differentiation *in situ*, than of differentiation below, and intrusion as a sulphide-norite magma. The direct igneous connection is the same in both cases.

Charles P. Berkey,* New York, N. Y.—Perhaps I ought not to speak on this subject, especially since I have never been in Sudbury, but it happens that I have to pass judgment about a good many other places that I have never visited, and it happens also that I have had a good deal to do with the examination of materials with the microscope, for the purpose of determining what has happened to them. A theory has to meet the facts revealed by the microscope, just as it has to meet the facts shown by the drill.

We are in danger of being confused by terms that have come to be ill defined because they have overlapped. Terms such as "magmatic" and "hydrothermal" overlap in such a way as to be particularly confusing at the present time. There are two terms, however, that are useful and that can be applied very systematically: those are the terms "primary" or "original," and the term "introduced," and it is interesting to examine these ores to determine how much evidence there is to support one or the other source of origin.

I have been especially interested in the numerous and excellent papers on Sudbury presented in the last few years, because in our laboratories at Columbia some of this work was done, many years ago, by Mr. Dickson and Mr. Knight. I felt interested to know whether, when

[9] For further consideration of this idea, see Allan M. Bateman: Magmatic Ore Deposits, Sudbury, Ont. *Economic Geology* (1917), **12**, 391.

* Professor of Geology, Columbia University.

they looked through the microscope, they were entirely mistaken or not. I am pretty well convinced that they were not mistaken, that they saw what they say they did, and described pretty well what they did see. But on examining some of their material, and some that we have received since, it appears to me that the microscopic evidence is perfectly clear that some of the sulphides are primary, and it is just as clear that some of it is introduced. One must then make a picture of this deposit that will admit that condition, no matter what prejudices one may have.

I do not see anything difficult about imagining a differentiation and solidification of some of the sulphides in the margin of this intrusion, as a part of the original rock, or a true magmatic differentiation. Nor is it difficult to suppose the rest of it to be introduced from the still unconsolidated residue, the end-product stuff that ought to have accumulated in the base and the center of the intrusion, furnishing surplus emanation matters that had to be disposed of. When the time came, they were ejected through the previously cooled and crystallized ore-bearing marginal portions of the mass, where they have been deposited in crush zones and other weaknesses and have replaced much original nonmetallic matter of the rock. Hence, in some of these ores you find minerals that are primary and in the same block other minerals that are introduced. The magmatic segregational process may even have continued to such a degree as to produce secondary granite.

This particular deposit seems to be the best illustration in the world of primary magmatic segregation of two sorts, perhaps fractional crystallization and liquation. I see no difficulty in supposing some of this sulphide to have separated in the bottom of the reservoir, very much as in a furnace, together with surplus matters that had to be disposed of later, some of which were then allowed to escape in solution. Perhaps the slumping of the whole mass gave the fracturing through which the solutions proceeded. Perhaps the upper portion of the mass, being more acid, became solid earlier, while the lower part, being more basic, remained more plastic or more vulnerable, so that when these liquid and gaseous substances finally escaped they found their way easier through those lower and marginal portions that were more receptive than the great granite cover.

Waldemar Lindgren,* Cambridge, Mass.—Two or three years ago, when examining some properties at Sudbury, I had occasion to look over a great many diamond drill records, and I found that in practically all cases the nickel and the copper began in small quantities at a rather definite level and increased gradually toward the bottom; the largest percentage of nickel and copper may not have been found exactly at

* Geologist, Massachusetts Institute of Technology.

the bottom, but somewhere near there. On examining the ore, however, you will find that it is not uniform in detail. Every observer in Sudbury knows that there are masses as big as a head, or a fist, of solid norite, which are cemented by high-grade ore; this occurrence is most frequent near the bottom. It is very common to find a rather smooth boulder of norite covered, as by a skin, with practically solid pyrrhotite, so that you can knock it off. This shows that the segregation could not have been a simple settling, as in a liquid magma, but proves that some of the norite was certainly solidified before the ore was deposited.

Hence, we find these conflicting facts: first, a gradual enrichment of the original material with depth; second, a lack of uniformity in the ore and the certainty that some norite, practically free from sulphides, has separated out before the ore. On further examination of the ores under the microscope, we certainly do find that they are later than the silicates, and that they are frequently accompanied by biotite. Biotite in small quantities is, I believe, quite characteristic as a late magmatic product.

So, from what little I have had to do with the matter, I have arrived at the conclusion that Longyear and Roberts are practically correct in assuming that the ores are magmatic, but they belong to a late magmatic period and have been formed or injected after part of the norite had been consolidated. There is no doubt about the fact that later changes have occurred, but I think they are rather unimportant.

L. C. Graton,* Cambridge, Mass. (written discussion†).—Whether one may accept or oppose the geological arguments and conclusions expressed in this paper, he must feel that in one respect, at least, the geologists who are its authors have afforded us a fine example of what a geological paper ought to be, in that not until after they had found the ore did they attempt to talk about hypotheses or origins or localizations.

The prime object of the geologist as a scientist is to find the truth. The prime object of the geologist as a practitioner is to find ore. The scientist will surely find more of the truth and find it more quickly if he has had experience in applying his theoretical ideas to the practical business and exacting test of ore-finding. And, on the other hand, the professional mining geologist cannot hope to be really successful (as contrasted with lucky) unless he possesses an acquaintance with, and respect for, the scientific principles of ore deposition as thus far ascertained and understood. When, as in the present instance, two young men, after having investigated and appraised the scientific aspects of the problem, deduce and decide upon a systematic and definite program of exploration which they back not only with their company's money but with their

* Professor of Mining Geology, Harvard University.

† Received Mar. 21, 1918.

own reputations as well, and when in direct consequence of the prosecution of such a program they disclose an orebody of the probable magnitude indicated, it looks to me like a pretty good case of combining theory and practice, science and application. It may be that the premises on which they proceeded were partly or wholly wrong; I may confess, indeed, that I am not in complete sympathy with some of them; but up to date we possess no more impressive or convincing test of a geological hypothesis than this one of actually applying it to a piece of ground and actually finding the predicted or expected conditions—what Van Hise has called "geology made to order."

In these circumstances, particularly, it seems to me that the degree of fairness with which the authors have briefly reviewed in this paper the various ideas of origin that have been proposed for the Sudbury ores, and the modesty and moderation with which they express their own preference for a particular one of these views, reflects, equally with the outcome of their activities in the field, a great deal of credit upon them.

The Relation of Sphalerite to Other Sulphides in Ores

BY L. P. TEAS,* M. A., ITHACA, N. Y.

(New York Meeting, February, 1918)

As sphalerite is such a common constituent of many types of ore, the present investigation was undertaken to determine what its relations are to the other minerals in the deposits, and also whether these are of any genetic significance.

The data presented herewith were obtained from a mineralographic study of about 200 ore specimens from some 43 different localities, represented by suites of specimens in the Cornell University collection. These, grouped according to their genesis, were as follows:

I. *Contact-metamorphic Deposits.*—Silver City, N. M.; Kelly, N. M.; Silver Bell, Ariz.; Bingham, Utah; Agaguca, Michoacan, Mex.; Matehuala, Mex.; Sombreretti mine, Mex.

II. *Deep-vein Zone Deposits.*—Mineral, Louisa Co., Va.; Edwards, N. Y.; Chestnut Yard, Va.; Allah Cooper mine, Louisa Co., Va.; Globe, Ariz.; Moyie, B. C.; Rossland, B. C.; Broken Hill, N.S.W.; Weedon, Que.[1]

III. *Intermediate-vein Zone.*—Park City, Utah; Leadville, Colo.; Butte, Mont.; Santa Barbara, Mex.; Red Cliff, Colo.; Burro Mountains, N. M.; Idaho Springs, Colo.; Blue River, Ore.; Rye, Colo.;[1] Slocan district, B. C.; Freiberg, Ger.; Clausthal, Ger.

IV. *Shallow-vein Zone.*—Ouray, Colo.; Goldfield, Nev., Zacatecas, Mex.; Field, B. C.; Kapnik, Austria; Frontenac mine, Kingston, Ont.

V. *Meteoric Water Deposits.*—Joplin, Mo.; Southwest, Wis.; Austinville, Va.; Crittenden County, Ky.; Ridgeburg, Pa.; Moresnet, Belgium.

It is not supposed that the investigation of such a limited number of occurrences may warrant conclusive and universal generalizations, but the conclusions reached are believed to be reliable in so far as the specimens that were examined are concerned.

Summary of Results

The main facts brought out by the study of the blende-bearing ores examined are as follows:

1. Chalcopyrite as minute triangular or rectangular dots, or as

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* Assistant in Geology, Cornell University.

[1] Placed in this group provisionally.

stringers, can be practically always found in sphalerite that has been deposited by ascending juvenile waters, the amount apparently varying somewhat directly with the temperature and pressure of formation. The dots show a strong tendency to group themselves along crystallographic directions.

2. Chalcopyrite, as minute dots or stringers was not found in sphalerite deposited by meteoric waters.

3. Sphalerite does not appear to carry silver compounds in visible amounts.

4. In all the ores examined, sphalerite is generally the first valuable sulphide and the second metallic sulphide deposited by ascending solutions.

5. Sphalerite deposited by meteoric waters does not occupy any definite position in the series of minerals deposited.

General Occurrence of Sphalerite

Sphalerite has been observed to occur in nature, as an original constituent of granite;[2] in vein deposits of all zones, in contact-metamorphic deposits, and in those formed by the action of meteoric waters. When deposited by solutions or vapors its precipitation may take place in cavities or by replacement.

One odd occurrence is in lignite,[3] and another as nodules in clay under a Michigan coal.[4]

Even in deposits of the same type, the occurrence of sphalerite may be somewhat variable.

In taking up the present discussion, it seems best to consider the deposits in groups of similar genetic character.

Contact-metamorphic Deposits

In the specimens examined, the sphalerite carries chalcopyrite, usually in the form of minute triangular, rectangular, or rounded dots, as well as stringers, which often follow crystallographic directions, their presence being most pronounced. These can usually be seen with a low-power objective (Fig. 1), but the use of a higher power often discloses great quantities of smaller dot clusters (Fig. 2). In many cases, larger areas of chalcopyrite may be present in the sphalerite, in addition to the dots, but this is the exception rather than the rule. Galena and pyrrhotite rarely occur in the same relation as the chalcopyrite, but

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[2] E. Rimann: Magmatische Ausscheidung von Zincblende in Granit. *Zeitschrift für praktische Geologie* (1910), **18,** 23.

[3] H. A. Wheeler: Note on an Occurrence of Blende in Lignite. *Transactions, St. Louis Academy of Science* (1895), **7,** 123.

[4] A. C. Lane: *Michigan Geological Survey* (1902), **8,** Pt. II, 24.

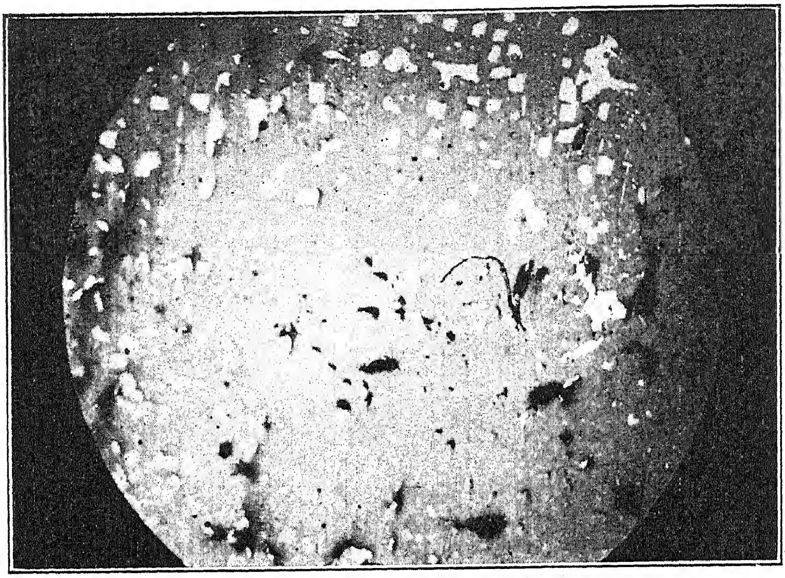

Fig. 1.—Rectangles, dots and stringers of chalcopyrite in sphalerite from Silver City, N. Mex. × 40.

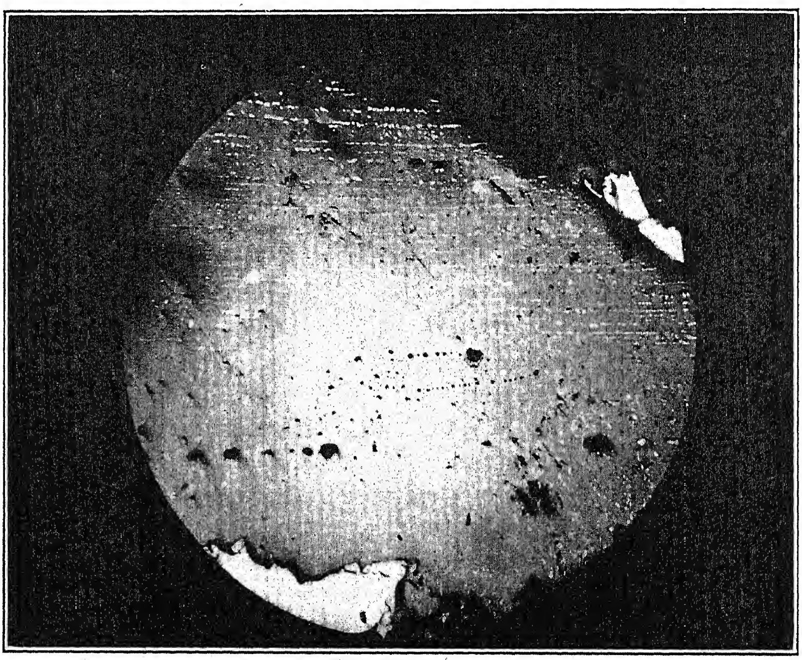

Fig. 2.—Development of dots and stringers of chalcopyrite, chiefly along two crystallographic directions in sphalerite, from Santa Barbara, Mex. × 40.

a case of the former was observed in some ore from Bingham Canyon, Utah, and of the latter from the Matehuala district, Mexico.

Pyrite, when present, seemed invariably to be the first sulphide deposited, while sphalerite in every case, except two, followed it. Thus at Matehuala, the pyrrhotite may have been earlier than the sphalerite, while at Hanover, N. M., the occurrence of corroded hematite needles in sphalerite seems to indicate a replacement of the former by the latter (Fig. 3).

The primary associates of the sphalerite in the specimens examined were restricted to chalcopyrite, galena and pyrrhotite, named in the

FIG. 3.—CORRODED HEMATITE NEEDLES IN SPHALERITE, HANOVER, N. MEX. × 52.

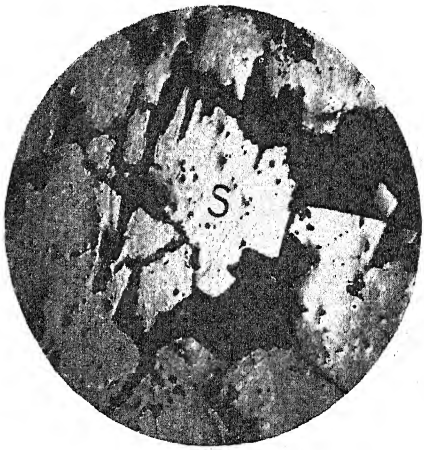

FIG. 4.—QUARTZ CUTTING SPHALERITE (S) AND APPARENTLY REPLACING IT IN PART. THE SPHALERITE CONTAINS NUMEROUS SMALL CHALCOPYRITE DOTS WHICH DO NOT SHOW IN THE ILLUSTRATION. HANOVER, N. MEX. × 30.

order of their importance. Pyrite at times seems undoubtedly replaced by sphalerite, but it also replaced gangue minerals.

In one specimen from Hanover, N. M. (Fig. 4), the sphalerite appeared to be replaced by quartz. The reasons suggesting this are that the quartz not only cuts the sphalerite in veins, but also penetrates it in a manner suggesting replacement.

DEEP-VEIN ZONE DEPOSITS

In this group, as compared with the preceding, there seemed to be a marked decrease in the intensity and regularity of distribution of the chalcopyrite dots within the sphalerite, and in some the dots appeared to be absent, but this may have been a local exception, or the grains of the specimen examined only may have been free from it.

The presence of pyrrhotite seemed to be unfavorable to the develop-

ment of chalcopyrite in sphalerite since it was often found in areas in which the former was lacking. This absence of chalcopyrite dots in the sphalerite might be explained, however, by assuming an order of crystallization different from that usually observed. Thus in specimens from the LeRoy mine at Rossland, B. C., the chalcopyrite appeared to replace pyrrhotite, while the small amount of sphalerite present was evidently later, but contained some small patches of pyrrhotite. It is possible that these are unreplaced fragments of the latter in the former. At this locality it seems that both pyrite and pyrrhotite at least, may be of several different generations, a fact that has been noted by both Drys-

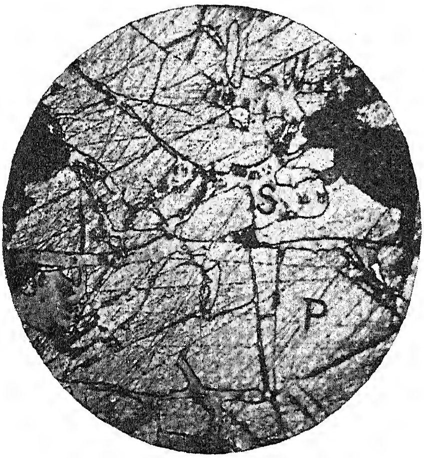

FIG. 5.—SPHALERITE (S) REPLACING PYRITE (P), FROM SOUTHWEST OF EDWARDS, N. Y. × 30.

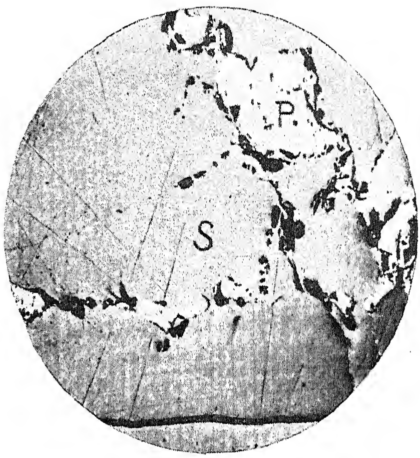

FIG. 6.—PYRRHOTITE (P) REPLACING SPHALERITE (S), RYE, COLO. × 30.

dale[5] and Bruce.[6] Each of these writers also notes that the sphalerite postdates the chalcopyrite.

When pyrite was present it was almost universally the first sulphide deposited. It was then followed by sphalerite, in one instance closely attended by pyrrhotite.

The sphalerite is replaced by chalcopyrite and galena, and was found replacing both quartz and pyrite, a good occurrence of the last being shown by ore from southwest of Edwards, N. Y. (Fig. 5).

INTERMEDIATE-VEIN ZONE

The development of chalcopyrite dots and stringers in the sphalerite was noticed in all specimens examined, but in those from the Ontario mine, Park City, Utah, they were by no means abundant. On the whole,

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[5] *Canada Geological Survey, Memoir* 77 (1915).

[6] *Report of British Columbia Minister of Mines* (1916), K 231.

the chalcopyrite dots seemed to be slightly more numerous than in ores of the deep zone, although this may have been merely a coincidence.

Wherever pyrite was present, it was found to antedate the sphalerite, the period of deposition of the two apparently being sometimes separated by that of gangue minerals.

Following the sphalerite came chalcopyrite, sometimes accompanied by pyrrhotite and after this galena followed by tetrahedrite.

Galena, tetrahedrite, chalcopyrite and possibly pyrrhotite were seen replacing the sphalerite, while the last named was found replacing pyrite, schist and some of the gangue minerals. Fig. 2 shows a remarkable and uniform development of chalcopyrite, from Santa Barbara, Mex. Fig. 6, from a vein in gneiss near Rye, Colo., shows sphalerite cut and replaced by pyrrhotite.

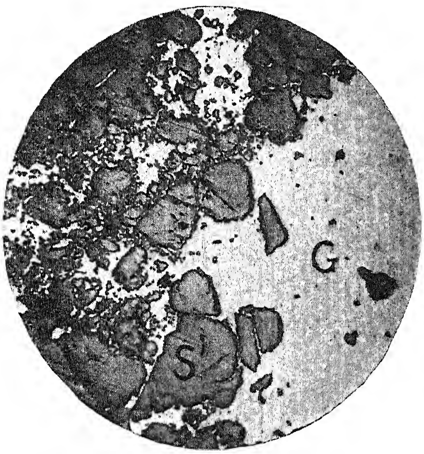

FIG. 7.—GALENA (G) REPLACING SPHALERITE (S), OURAY, COLO. × 30.

FIG. 8.—SPHALERITE (S), REPLACING DOLOMITE (BLACK), MONARCH MINE, FIELD, B. C. × 30.

SHALLOW-VEIN ZONE

Although the chalcopyrite dots were by no means lacking in ores of this group, there seemed to be a decided decrease in their number and size; neither was their persistence along cleavage directions in the sphalerite as striking as in the preceding groups.

Pyrite, when present, was the first sulphide to form, but when pyrite was absent sphalerite was the first. Chalcopyrite appears in some cases to be contemporaneous with the galena, and may occur in the same veinlets with it. Tetrahedrite is common, but was a late precipitation. It is more closely associated with the galena than with the sphalerite.

In general, the galena and tetrahedrite replace the sphalerite.

In one specimen from Kapnik, Hungary, the chalcopyrite in medium-sized areas is in contact with the sphalerite, while in the latter, near the

boundary, are many minute dots of the former. These dots also occur in the sphalerite, on either side of chalcopyrite veinlets.

A good example of replacement of sphalerite by galena is shown in Fig. 7 from Ouray, Colo.

Fig. 8 is a specimen from the Monarch mine at Field, B. C., showing the replacement of dolomite by sphalerite. No intrusive rock is found near the orebody, but the sphalerite contains dots of chalcopyrite.

Deposits from Meteoric Waters

The chalcopyrite dots and stringers found almost constantly in ores deposited by ascending solutions seem to be entirely lacking in those ores whose concentration is commonly regarded as the work of meteoric waters.

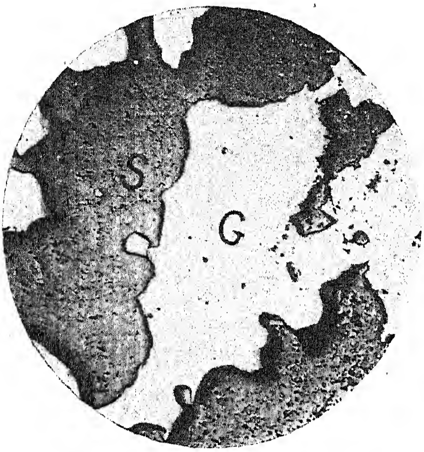

Fig. 9.—Galena (G) replacing (?) sphalerite (S), from Moresnet, Belgium. × 30.

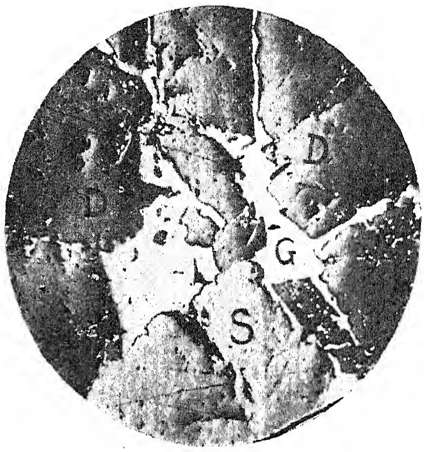

Fig. 10.—Galena (G) replacing dolomite (D) and in part sphalerite (S), from Austinville, Va. × 30.

In most of these deposits, chalcopyrite is entirely absent, but in some specimens from Joplin, Mo., sphenoids of chalcopyrite were noticed both on the outside of the sphalerite crystals and within them.

The order of crystallization in this group of deposits appears to be indefinite. Sphalerite is often the first valuable sulphide to crystallize, and at times may precede the marcasite. In other instances, galena seemed to have preceded the sphalerite, but at other times their relationship was not capable of definite interpretation. Again, at others there may be an alternation of the zinc and iron sulphides as at Moresnet, Belgium.

Galena occasionally appears to replace the sphalerite, and this sometimes seems to be true of specimens that show a crustified structure. Thus Fig. 9 is from a specimen of crustified ore from Moresnet, Belgium.

The specimen is made up of alternating bands of zinc sulphide and iron sulphide, but along certain bands of the former the hand specimen shows grains of galena. Under the microscope, however, the relation of the two is such as to show that the galena may in part replace the sphalerite.

In Fig. 10, both sphalerite and galena replace the dolomite, but the second is later than the first.

Fig. 11 shows sphalerite from Joplin, Mo., containing triangular crystals of chalcopyrite, but no dots of the latter, and the crystals are around the edge of the sphalerite grains.

Discussion of Results

In the foregoing statements, a few facts of importance seem to stand out and warrant further comment, viz:

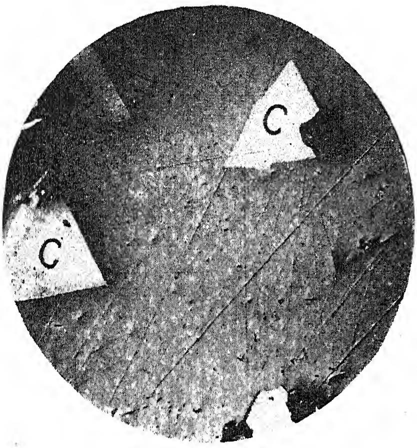

Fig. 11.—Chalcopyrite crystals in sphalerite, Joplin, Mo. × 30.

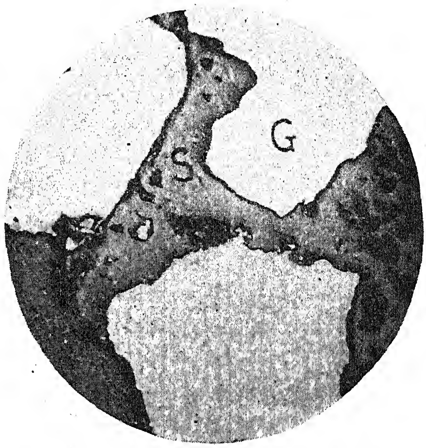

Fig. 12.—Galena (G) and sphalerite (S), from Mineral Point, Wis. The sphalerite may be later. × 30.

1. The occurrence of chalcopyrite as dots or stringers in the sphalerite.

2. The comparative absence of many minerals as primary associates of the sphalerite.

3. The prevalence of sphalerite as the first valuable sulphide to crystallize or as the second metallic sulphide.

4. The replacement of sphalerite by metallic minerals.

5. The possible replacement of sphalerite by non-metallic minerals.

These may be considered in more detail:

1. *Chalcopyrite Impregnations.*—The chalcopyrite dots so widely noticed in this paper have been casually mentioned by several writers. Thus Dolmage found them in the ore from Tyee, Vancouver Island;[7]

[7] V. Dolmage: Peculiar Type of Ore from the Tyee Copper Deposit of Vancouver Island. *Economic Geology* (1916), **11**, 390–394.

Graton and Murdock also observed them from several localities.[8] They were likewise noted by Wolcott, in ores from Clear Creek County, Colo.;[9] by Thompson, from Ducktown, Tenn.;[10] by Overbeck in Maryland ores;[11] and by Guild in blende-bearing silver ores.[12]

If, then, there is such a widespread occurrence of copper in sphalerite, one would expect to find it in analyses of the latter mineral, and such is the case.

In Table 1, compiled from analyses quoted by Hintze,[13] there are given a list of a number of common metallic minerals, the number of analyses, and the percentage of these showing copper and other impurities which bring out the fact that it is more abundant in pyrite and sphalerite than any of the others.

TABLE 1.—*Impurities in Sphalerite and Other Minerals*

Mineral	Number Specimen Anal	Copper		Silver		Lead		Zinc	
			Per Cent.		Per Cent.		Per Cent.		Per Cent.
Sphalerite......	81	34	43	6	7	12	14		
Galena.........	34	8	23	12	30	....	.....	12	30
Pyrite.........	37	23	60	....	.....	....	.....	7	18
Pyrargyrite....	38	....	.....	....	.....	....	.....	2	5
Gold..........	171	32	16	...	.....	....	.....	3	1
Polybasite.....	12	....	.....	....	.....	....	.....	0	0
Arsenopyrite...	85	3	3	....	.....	....	.....	2	2
Chalcocite.....	31	....	.....	....	.....	....	.....	2	7
Chalcopyrite...	43	....	.....	2	5	3	7		
Tetrahedrite...	170	....	.....	123	70	28	16	118	65

It is not known, of course, whether these impurities represent replacements, mechanical inclusions or intergrowths.

If we could eliminate all those sphalerite analyses representing occurrences deposited by meteoric waters, the percentage of cupriferous sphalerite would undoubtedly be much greater. We do not know, of course, the exact relation of the copper to the mineral analyzed in each

[8] L. C. Graton and J. Murdock: Sulphide Ores of Copper. *Trans.* (1914), **45**, 26–93.

[9] Unpublished manuscript of a Master's thesis, Cornell University.

[10] A. P. Thompson: On the Relation of Pyrrhotite to Chalcopyrite and Other Sulphides. *Economic Geology* (1914), **9**, 153–174.

[11] R. M. Overbeck: Metallographic Study of the Copper Ores of Maryland. *Economic Geology* (1916), **11**, 151–178.

[12] F. N. Guild: Microscopic Study of the Silver Ores and Their Associated Minerals. *Economic Geology* (1917), **12**, 297–353.

[13] C. Hintze: *Handbuch der Mineralogie.*

case, but its affinity for zinc seems rather striking, and is even more pronounced in the microscopic study of the ores.

Considering the relation existing between the relative development of chalcopyrite and the genetic type of ore, we see from Table 2 that the contact-metamorphic deposits showed an excellent development of the dots with a decreased occurrence in the deep-vein zone type, and an increase again in the intermediate-vein zone type, while in the upper-vein zone ores, the dots were much less numerous, and in some cases required a high power for their recognition.

TABLE 2.—*Distribution of Chalcopyrite Dots in Various Deposits*

Deposits	Number of Localities*	Chalcopyrite Found In	Relative Abundance
Meteoric	8	0	none
Contact metamorphic	8	8	very numerous
Deep-vein zone	11	10	fairly numerous
Intermediate-vein zone	11	11	very numerous
Shallow-vein zone	5	5	small, few

* At least two polished specimens were examined from each locality.

In the deposits concentrated by meteoric waters, the absence of the dots is remarkable, even though some of the deposits contained chalcopyrite.

In this connection, it may be of interest to refer to the case of the Frontenac mine, near Kingston, Ont.;[14] regarding whose origin some doubt has been expressed. Uglow suggests that the fluorite found in the group of veins of which this is one may be of magmatic origin, while the calcite, galena, and sphalerite have been obtained from the surrounding rocks. The sphalerite, however, shows dots of chalcopyrite, but not in abundance.

We may well ask why the chalcopyrite seems to favor the sphalerite, often to the exclusion of other equally available minerals. There seems to be nothing in the affinity of copper, or of copper and iron, for zinc, to warrant it, and nothing experimental seems to have been done along this line.

Galena is certainly as brittle as sphalerite, and offers more ready access for solutions along its cleavages, yet rarely does chalcopyrite penetrate galena to any extent in the dot form, though it may sometimes be later than the galena. That chalcopyrite is not entirely averse to lead is shown by the fact that it may be sometimes associated with galena, and galena with chalcopyrite enter together in many upper-zone deposits.

[14] W. L. Uglow: Origin of Certain Ore Deposits. *Economic Geology* (1916), **11**, 87–92.

In order to find out whether porosity might be a factor in causing the association of sphalerite and chalcopyrite, a determination of the porosity of selected specimens of galena and sphalerite from Joplin, Mo., was made, for it was thought that since the galena is the most common associate of the sphalerite, it would be the best mineral with which to make a porosity comparison.

The results are as follows:

	Sphalerite, Per Cent.	Galena, Per Cent.
No. 1....................	0.21	0.48
No. 2....................	0.26	0.49

From this we see that as far as the relative porosities are concerned the galena affords the better host for the chalcopyrite. Hence we must conclude that the porosity of the sphalerite has nothing to do with its impregnation by chalcopyrite.

In the case of ores deposited by ascending waters, it is probable that the presence of heat and pressure may aid the chalcopyrite to penetrate the sphalerite, and replace it. This it does along sub-microscopic channels, being deposited either in straight lines (Fig. 2), or in spots (Fig. 1). Sometimes the spots taper off along the lines on which they entered.

Since the chalcopyrite dots are more abundant in the deep-vein zone deposits, it would seem that heat and pressure are a factor governing the extent of the impregnation.

In the case of deposits concentrated by meteoric waters, we are dealing with solutions under less temperature and pressure. Such solutions might not, therefore, have the power to easily impregnate the dense sphalerite, even though they carried copper.

As a matter of fact, the copper content of this type of deposits is small, although excellent sphenoids are found coating and sometimes even within the sphalerite specimens from Joplin, Mo.

These crystals may follow parallel lines of the sphalerite, possibly cleavage lines. The presence of these large chalcopyrite crystals (Fig. 11) can perhaps be explained when we remember that successive additions of sphalerite might have covered up successive crusts of chalcopyrite. But even here, though the chalcopyrite sometimes is within the sphalerite, there are none of the characteristic feeding stringers found in the deposits of juvenile water origin.

While the occurrence of chalcopyrite in sphalerite seems to have been curiously persistent in the specimens examined by the writer, it is evident that there may be reasons for the absence of chalcopyrite in some cases. These are:

(*a*) The total absence of copper in the ore-bearing solutions.

(*b*) Copper, though present, might have been precipitated before the introduction of the sphalerite. While this case is rare, since chalcopyrite

nearly always postdates the sphalerite, the determination of the order of the two in any deposit is necessary.

(*c*) The copper may escape observation because the dots are so small.

(*d*) More than one specimen from a locality should be examined, to avoid overlooking any copper.

(*e*) Sphalerite, if secondary, might show the characteristics of a supergene mineral, although occurring in a primarily hypogene deposit.

(*f*) The sphalerite might occur in such small quantities that surrounding minerals may have prevented its attack by the chalcopyrite solutions.

Application of Principle.—It may seem a little rash to draw any definite conclusions from the examination of the limited number of occurrences covered by this paper; nevertheless, if the principle suggested is correct it might be possible to:

(*a*) Differentiate between a primary ore deposited by ascending or descending waters.

(*b*) Indicate the character of the solutions that had deposited an ore, now of metamorphosed character.

(*c*) Identify secondary from primary sphalerite in a deposit formed initially by ascending waters.

Galena-pyrrhotite Impregnations.—In a few specimens, minute dots of galena and pyrrhotite were found in the sphalerite, although in much smaller quantities than those of chalcopyrite, but in every case the deposits were of the deep-vein zone type. At Idaho Springs, some tetrahedrite dots have also been found in the sphalerite, but this seems rare.

Relative Isolation of the Sphalerite.—In direct contrast to the close association of chalcopyrite with sphalerite, and the replacement of the latter by the former, we see few other metallic minerals showing similar relationship.

Many writers have been led to believe, by assays of sphalerite ore with which only a small amount of galena was associated, that the silver, gold, antimony and similar metals found in the assay were contained as small grains in the sphalerite. Perhaps it is so, but magnifications up to 100 diameters have not disclosed them, while much less magnification has shown numerous compounds of these metals to be present in galena, and has also shown the prevalence of chalcopyrite, and in some cases pyrrhotite, in the sphalerite.

Reference to Table 1 shows how few elements were found in the sphalerite aside from copper and lead, and how little zinc was noted in other minerals.

Evidence furnished by Bastin, Wolcott and others shows that even in deposits characterized by silver minerals, these compounds show a distinct aversion to the sphalerite; further, the experiments of Bastin and Palmer[15] have shown that sphalerite acted only weakly as a precipitant

[15] C. Palmer and E. S. Bastin: Metallic Minerals as Precipitants of Silver and Gold. *Economic Geology* (1913), 8, 160.

of gold from slightly acid $AuCl_2$ solutions, while it was entirely inactive toward the silver, in a silver chloride solution.

F. C. Lincoln[16] found that sphalerite was the fourth most important associate of gold in 585 veins which he examined megascopically. Of 163 occurrences of sphalerite in the same vein with gold, there seemed to be some relation in 69 cases. In 18 of these the gold was disseminated in the sphalerite, in five it was on the sphalerite, in seven intergrown with it, and in 37 with it.

Bastin[17] found that polybasite, though often in the same section with sphalerite, and postdating it, preferred the quartz-galena contact. Moreover, the silver mineral replaced the galena but left the sphalerite un-

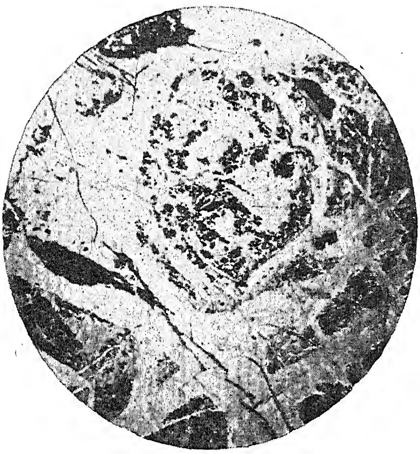

FIG. 13.—SPHALERITE (LIGHT) REPLACED BY CHALCOCITE (DARK), BURRO MTS., N. MEX. × 30.

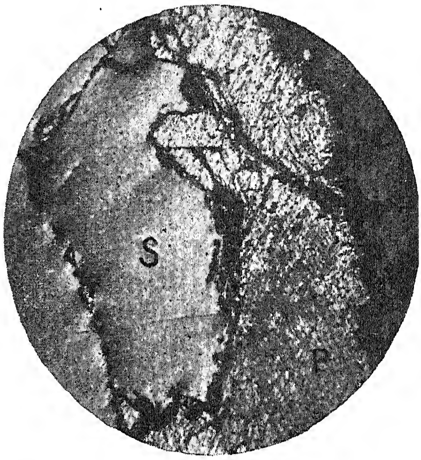

FIG. 14.—PYRITE (P) REPLACING SPHALERITE (S), MIFFLIN, WIS. × 30.

touched. Similar relationships are described by Bastin[18] from Clear Creek and Gilpin Counties.

At Butte, Mont., sphalerite may be often intimately associated with pyrite, bornite, chalcocite and galena, but rarely with enargite, and at Park City, Boutwell has commented on the non-association of sphalerite and tetrahedrite.

There seem, however, to be occasional exceptions, as shown by graphic

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[16] F. C. Lincoln: Certain Natural Associations of Gold. *Economic Geology* (1911), **6**, 247.

[17] E. S. Bastin: Metasomatism in Downward Sulphide Enrichment. *Economic Geology* (1913), **8**, 54.

[18] E. S. Bastin: Economic Geology of Gilpin County and Adjacent Parts of Clear Creek and Boulder Counties, Colorado. *U. S. Geological Survey Professional Paper* 94 (1917).

intergrowths of sphalerite and jamesonite at Zimapan, Mex.[19] or of pearcite and sphalerite in Clear Creek County, Colorado.[20] In this last named area, enargite, polyargyrite, and polybasite also replace the sphalerite. These unusual cases may be due to peculiar conditions of temperature and pressure.

Order of Crystallization.—As previously pointed out, in all the specimens examined, it seems to be almost universally true that sphalerite is the first valuable, and the second metallic sulphide to crystallize from ascending solutions. This fact has been noted by other writers for Butte, Mont.; Ducktown, Tenn.: Ely, Vt.; Capleton, Que.; Gordonsville, Va.; and Idaho Springs district, Colo., etc.

Great care must be exercised, of course, in studying ores for the purpose of determining the order of succession, but the following criteria seem to be fairly reliable: (*a*) Younger minerals may cut older ones in veinlets; (*b*) a younger mineral may fill cleavage cracks in the older; (*c*) a mineral following well-defined directions as dots or stringers in another is the younger; (*d*) a later mineral may occur along the contact of two others, and even replace one or both along its boundaries; (*e*) if possible, a large hand specimen should always be examined in connection with the polished pieces.

The mere surrounding of one mineral by another, as seen in the plane surface examined, is not necessarily definite proof that the inclusion is the older.

In the meteoric water deposits, different conditions prevail, and we might look for a different order of crystallization, provided all substances were present in the same solution. Galena might then be deposited first, followed by sphalerite. Siebenthal found that this is generally true in Missouri and Arkansas, but most of his examples were from vugs. But Bain, Grant, and Ulrich, in Wisconsin, Illinois, and Kentucky, respectively, found the sphalerite often as the first product. However, they mention the recurrence of the sphalerite and galena in several stages, the evidence also being taken from vugs.

Microscopic evidence seems to be also at variance, for in some cases the youth of the galena is shown by its occurrence as veins in the sphalerite, elsewhere the sphalerite appears to be cutting the galena, or again contemporaneity of deposition seems to rule.

As there appears to be little chance for any great quantity of secondary galena to have formed, we cannot ascribe the varying relationships to this. Our only recourse is to credit the varying observations and assume that as the deposition of the lead and zinc was, in some cases at least,

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[19] W. Lindgren and W. L. Whitehead: Deposit of Jamesonite near Zimapan, Mexico. *Economic Geology* (1914), **9**, 443.

[20] Wolcott: *Loc. cit.*

more or less continuous, there may have been many overlapping generations, and hence varying associations.

Further, the relative amounts of lead and zinc in a solution would largely determine their order of deposition.

4. *Sphalerite Replaced by Metallics.*—The author found sphalerite replaced by galena, tetrahedrite, chalcopyrite, and pyrrhotite. It has also been found replaced by chalcocite[21] (Fig. 13), covellite,[22] and pearcite,[23] bornite, stromeyerite,[24] and ruby silver.[24]

5. *Sphalerite Replaced by Non-metallics.*—The replacement of sulphides by non-metallics has been rarely noted hitherto, although one undoubted case has been described.[25] In this work one analogous case has come under the writer's notice in which quartz appears to be replacing sphalerite (Fig. 12).

Conclusions

The foregoing facts seem to warrant the following conclusions:

Sphalerite in General.—1. Silver compounds were not noted in any of the specimens of sphalerite, and observations by others indicate that they are rare.

2. Sphalerite may replace calcite, dolomite, quartz, pyrite, marcasite, hematite, and pyrrhotite; it may be replaced by galena, tetrahedrite, chalcopyrite, chalcocite, bornite, pearcite, stromeyerite, and ruby silver.

Sphalerite from Meteoric Waters.—3. This type was marked by complete absence of chalcopyrite dots in the sphalerite.

4. No uniform order of deposition of sphalerite, galena, and marcasite was noted.

Sphalerite of Hypogene Origin.—5. Chalcopyrite dots and stringers are generally associated with the sphalerite. They are most numerous in contact-metamorphic deposits.

6. Sphalerite in the occurrences examined is with one exception the first valuable, and second metallic sulphide deposited.

In conclusion, the writer wishes to express his appreciation to Prof. H. Ries and Prof. R. E. Somers, for suggestions and criticisms made during the course of the work.

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[21] R. E. Somers: Geology of the Burro Mountains Copper District, New Mexico *Trans.* (1915), **52**, 631.

[22] R. M. Overbeck: Metallographic Study of the Copper Ores of Maryland. *Economic Geology* (1916), **11**, 151–178.

[23] Wolcott: *Loc. cit.*

[24] Recorded by F. N. Guild (*Economic Geology* (1917), **12**, 297–353) in a paper that appeared as the present one was sent to press.

[25] H. N. Wolcott: Replacement of Sulphides by Quartz. *Trans.* (1918), **58**, 385.

DISCUSSION

THOMAS L. WATSON,* Charlottesville, Va. (written discussion†).—Sphalerite, as is well known, occurs not only as a common constituent of many types of ore deposits formed under widely varying geologic conditions, but its sulphide mineral associates comprise a goodly number of species. In the investigation by Mr. Teas, data were obtained from a mineralographic study of about 200 ore specimens from 43 different localities grouped according to their genesis as follows: (1) Contact-metamorphic deposits, (2) deep-vein zone deposits, (3) intermediate-vein zone deposits, (4) shallow-vein zone deposits, (5) meteoric water deposits. The object of the study was to determine the relations of sphalerite to the associated sulphide minerals and their possible genetic significance.

As a result of the investigation, Mr. Teas has deduced several important conclusions. Probably the one of largest interest and value was that sphalerite formed from magmatic waters, including contact-metamorphic deposits, could be distinguished, for the cases investigated at least, from sphalerite formed from meteoric waters, by development in the former of minute triangular or rectangular dots or stringers of chalcopyrite. Although chalcopyrite inclusions in sphalerite had been noted by previous observers, the probable significance of their apparent general occurrence in sphalerite of certain types of ore deposits and their absence from others was unknown.

The large number of ore specimens studied from more than 40 different localities in the United States and foreign countries, representing the principal genetic types of sphalerite-bearing deposits, gives considerable weight to the conclusions reached by the author. Should the conclusion drawn by Mr. Teas become generally applicable, a laboratory criterion of much value will have been established for distinguishing between sphalerite formed from juvenile and that from meteoric waters.

The principle seems applicable not only to sulphide deposits in which sphalerite is the principal constituent but to those in which it occurs as a very subordinate one, as shown by the study of ore specimens from one of the principal pyrite mines in Virginia. It may be possible also that the principle will have important application in differentiating primary from secondary sphalerite occurring in the same deposit formed from magmatic waters, although there have been comparatively few well-authenticated cases of secondary deposition of sphalerite. Furthermore, the records show the occurrence of secondary sphalerite in rocks other than limestones to be rare. Nevertheless, it would be of interest and

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† Received Feb. 15, 1918.

possibly productive of results to extend the investigation into this phase of sphalerite genesis.

Sphalerite is a frequent constituent in many of the sulphide deposits of the southeast Atlantic States, and in some, especially in those of Virginia and Tennessee, it is the dominant sulphide mineral. Genetically, several different types of deposits are represented, which for purposes of this discussion may be broadly grouped into (1) those formed from meteoric waters, and (2) those formed either directly or indirectly from juvenile waters. The zinc deposits of the east Tennessee valley of Virginia and Tennessee are usually regarded as having formed from meteoric waters, while those deposits occurring in the metamorphic crystalline rocks east of the Blue Ridge in Virginia owe their origin to magmatic waters. Specimens of ores from each of these types of sphalerite-bearing deposits in Virginia were included in Mr. Teas' investigation, with the result that the sphalerite of the two groups was differentiated on the basis of the principle stated, which confirms our knowledge previously gained from the facts of field occurrence, etc.

Mr. Teas has made an important contribution to our knowledge of sphalerite-bearing ore deposits, and it is to be hoped that the investigation will be continued in order to test the reliability and value of the conclusion as a safe laboratory criterion for differentiating between ore deposits containing sphalerite formed by magmatic waters and those deposited by meteoric waters.

L. C. Graton,* Cambridge, Mass. (written discussion†).—The method of arriving at conclusions in regard to ores and ore deposition through the microscopic study of a suite of specimens, ordinarily collected by someone else, more or less representative of the occurrences from which they come, labeled carefully or carelessly, completely or incompletely, as the case may be, is a method that possesses obvious dangers. It is an attractive method, and it is a feasible method for gaining both experience and geological results, particularly by the younger men in our universities. It is farthest from my intention to discourage this practice or to minimize the value of conclusions that may be reached by its means. I wish only to point out that such conclusions must necessarily be regarded as resting on somewhat incomplete or possibly sometimes erroneous foundations and therefore must be accepted and used with a certain reserve and caution. In general, the reliability of results attained by this method is likely to vary in direct proportion to the individual investigator's personal experience with the field relations, that is to say, the broad geological relations, of the type of deposit under examination.

Mr. Teas has produced by the use of this method what seems to me

* Professor of Mining Geology, Harvard University.

† Received Mar. 21, 1918.

a very good paper. It is gratifying to find that a number of conclusions which my associates and I have reached from the field and laboratory study of sphalerite-bearing copper ores find support in the results of his more intensive study of sphalerite in what are mainly zinc ores. While some of his conclusions may eventually suffer modification or even reversal, as happens, indeed, to the work of nearly all of us, his survey of this field and his summary of its features and its significance cannot fail to be helpful as well as an incentive to further study in this direction.

In one particular I venture to point out what seems to me an unfounded deduction and a possible illustration of the dangers that may attend the "specimen" method of investigation. I refer to the implication that the origin of a sphalerite-bearing ore, viz., whether of meteoric origin or produced by ascending solutions of deep-seated source, is indicated by the absence or presence, respectively, of small inclusions of chalcopyrite in the zinc sulphide. Mr. Teas studies specimens from a number of occurrences which, upon whatever independent evidence is available to him, he concludes were formed by meteoric waters; in these he finds certain characteristics in the sphalerite. He also studies specimens from a number of other deposits which he or others have concluded were produced by ascending, juvenile waters; and in the sphalerite of these he finds other characteristics.

If the original distinction assumed as to origin is correct and if, as the discussion by Dr. Watson has noted, Mr. Teas' finding of chalc pyrite in one case and none in the other, proves to be borne out by further evidence and study, then he certainly has afforded us a valuable and simple means of distinguishing between meteoric origin and magmatic origin in any new case which contains sphalerite that may come to attention. But if it should turn out that the group of deposits which he has thought are of meteoric origin are actually not of meteoric origin, or those which he has regarded as of juvenile origin are not to be so classed, then this difference between absence of chalcopyrite in one case and its presence in the other certainly does not mean that one group of deposits is of meteoric and the other is of magmatic origin. In other words, the conclusion is no more compelling or convincing than the initial premise on which it rests. And the observed difference with regard to chalcopyrite is simply one evidence of certain differences in mode of deposition of the two classes of deposits; it does not necessarily and inherently mean the difference between magmatic and meteoric solutions any more than it necessarily and inherently means the difference between acid and alkaline, or weak and concentrated solutions. One thing which it pretty evidently does mean, however, is that in one case, copper was available in the solution whereas in the other case probably little or no copper was available. And perhaps that is the only thing it does mean.

In connection with this subject it may be added that in certain in-

stances that have come under my observation where the central part of a district or of a single orebody yields ores worked for copper, the accompanying black, iron-rich sphalerite commonly carries included particles of chalcopyrite; but on the outlying edges of the district or deposit, where copper values are lower or wanting, the sphalerite may be lighter in color because lower in iron content, and may be quite free of chalcopyrite inclusions. Yet no one, I believe, could successfully maintain that the ores in the two situations differ essentially in origin.

H. Ries,* Ithaca, N. Y. (written discussion†).—The permanent establishment of any criterion will, of course, depend on whether the fundamental facts on which it is based are correct, and no theory can be accepted as the true one until it has stood the test of searching criticism. It seems to me that any one who reads Mr. Teas' paper carefully will see that he has assumed a somewhat conservative attitude. The results which he has presented are based upon a somewhat extensive series of specimens, collected in nearly every case by persons of known responsibility, and the laboratory study consisted not merely of an examination of polished chips, but of all the hand specimens, as well as the literature bearing on the deposits considered. The origin of the different deposits had to be determined in practically every case from the statements of reliable authorities, and it is perfectly safe to say, as Mr. Graton does, that we may find some of these genetic classifications to be incorrect, but, for that matter, the same might apply to some of the determinations of mineralographers.

I believe, however, that Mr. Teas was warranted in assuming that most of the determinations of origin were probably correct, and that the observed phenomena were sufficiently persistent to warrant placing them on record. He recognizes, however, that the suggestion which he advances may require further corroboration, for he says: "It is not supposed that the investigation of such a limited number of occurrences may warrant conclusive and universal generalizations, but the conclusions reached are believed to be reliable so far as the specimens that were examined are concerned."

On a later page, he remarks: "It may be a little rash to draw any definite conclusions from the examination of the limited number of occurrences covered by this paper; nevertheless, if the principle suggested is correct it might be possible to draw the following conclusions," etc.

The fact therefore remains, that in deposits usually regarded as of magmatic origin, the sphalerite so often shows these curious chalcopyrite inclusions, while none were observed in sphalerite usually regarded as being deposited by meteoric waters.

* Professor of Geology, Cornell University.

† Received April 9, 1918.

The study of mineralography is a most attractive one, but it is, of course, one that should be pursued with caution. In many cases, it is an indispensable aid to field study, but this is not intended to say that it cannot be used for the solution of problems in the laboratory independent of field work, for I believe it can. One danger, of course, lies in attempting to draw conclusions from one or two polished chips alone. This is sometimes safe, where the evidence is exceedingly clear; at other times it is not, and so the investigator must use very careful judgment. I must confess that some of the published illustrations of polished ore surfaces do not, in my opinion, always show what the authors have claimed for them.

Pyrite and Pyrrhotite Resources of Ducktown, Tenn.

BY JOSEPH H. TAYLOR, ISABELLA, TENN.

(New York Meeting, February, 1918)

THE Ducktown district is in the extreme southeastern corner of Tennessee, its principal railroad point being Copperhill, on the Blue Ridge division of the Louisville & Nashville Railroad, midway between Knoxville, Tenn., and Atlanta, Ga.

The ore deposits were discovered about 1849 and development work was begun in the early fifties. Only the "black copper" ores, products of secondary enrichment, from beneath the gossan outcrops and overlying the massive sulphide deposits, were then mined and smelted for their copper content. Upon their exhaustion, attention was directed to the treatment of the pyritic ore remaining, resulting in the devising of a process consisting of open-heap roasting, followed by blast-furnace smelting, which was practised until 1903, when semi-pyritic smelting was adopted.

In 1908, the companies operating in the district, on account of litigation brought about by alleged smoke damage to forests and vegetation in the adjoining counties of Georgia, were compelled to erect enormous acid plants to prevent the escape of the sulphur dioxide produced in the smelting operations. The utilization of this sulphur dioxide in the manufacture of sulphuric acid as a byproduct has added to the revenues of the companies, and at the same time has furnished a valuable source of supply of sulphuric acid to the fertilizer trade of the South, and more recently to the manufacturers of explosives for use in the production of war munitions.

The steadily increasing demand for sulphuric acid for the manufacture of fertilizers and explosives, together with the decreasing imports of pyrites, from which the acid is generally produced, now makes it imperative that greatly extended resources of pyrite be developed. While the Ducktown deposits do not predominate in pyrite, they do contain an inexhaustible supply of pyrrhotite, admixed with pyrite, which can be satisfactorily employed to supplement or substitute for pyrite in acid making.

The deposits consist of lenticular bodies of ore, more or less connected, the longer horizontal axes of which extend from northeast to southwest. The bodies vary in length from less than 1000 ft. to a mile or more, and vary in width from a few feet to a hundred or more. Some of the deposits have been explored in depth to more than 1000 ft. and their limits have thus far not been attained. In general, the ore dips at an angle greater than 60°, but there are many exceptions to this. All of these deposits lie within a region 7 miles long and slightly more than a mile in width.

The most northerly of the mines, known as the East Tennessee, has a longitudinal extent of approximately 600 ft., striking North 50° East and dipping minus 70° to the southeast. There is a decided longitudinal fold in the orebody. The ore produced is comparatively high in copper, more than 3 per cent.; but low in sulphur, about 12 per cent. The ore consists of pyrrhotite and chalcopyrite in quartz, with hornblende, talc, mica-schist, and other lime silicates. The resources of the mine are not great.

To the southwest of the East Tennessee mine, and having the same general strike and dip, but no traceable connection, is the London mine. The ore produced is pyrrhotite, with some pyrite and chalcopyrite, in quartz, and is mostly used for fluxing basic ores.

To the southwest of the London mine is the Burra Burra, having the same strike and dip. This mine, from the Burra Burra and McPherson shafts, produces the largest tonnage of any of the district. The ore is pyrrhotite, plentifully intermixed with crystals of pyrite and some chalcopyrite. The sulphur content is between 25 and 30 per cent. and the copper is less than 2 per cent. The orebody is nearly 3000 ft. long and varies from a few feet to a maximum of 150 ft. in thickness, the latter being across a longitudinal fold. The workings extend to a depth of over 1000 ft.

South of the southwest extremity of the Burra Burra mine is a small deposit known as the Culchote. No sulphide has been mined, but the deposit has been proved by diamond-drilling to be similar to the Burra Burra.

Somewhat more than a mile to the southeast of the Burra Burra mine is the Isabella-Eureka orebody. This is in the form of a large anticline, with a fault longitudinally along the crest. The Isabella part is thrown to the northeast and dips to the southeast; the Eureka part is thrown to the southwest and dips to the northwest. The ore is mostly pyrrhotite, well intermixed with pyrite and but little chalcopyrite, a small amount of quartz and lime silicates being present. The sulphur content is approximately 30 per cent. and the copper less than 1 per cent. Very little development work has been done, although there are two shafts to depths of 200 ft. and the deposit has been diamond-drilled to a depth of 500 ft. As the ore has been found to be wide near the surface, as well

as where crosscut by diamond-drilling, there are probably more than ten million tons and perhaps many times that amount of ore in the deposit.

About 2 miles to the southwest of the Isabella-Eureka deposit is the Mary-Polk County deposit, which shows more faulting and folding than any of the other deposits of the district. To the northeast is the Calloway mine (at present idle) which has no traceable connection with the main orebody, and to the northwest is another outcrop whose relation to the main orebody is unknown. The ore is continuous through the Mary and Polk County mines for approximately half a mile in a northeast and southwest course. Widths vary from a few feet to a hundred or more, and the deepest shaft shows ore at more than 1100 ft. below the surface. Pyrrhotite is the predominant mineral, carrying chalcopyrite and sphalerite but practically no pyrite. The gangue is quartz, calcite, hornblende, and other lime silicates. The ore runs less than 20 per cent. sulphur and between 2 and 3 per cent copper; it also contains zinc, the percentage of which is greater than the copper. The deposit will undoubtedly produce many million tons of ore of this grade.

To the southwest of the Burra Burra, and about a mile northwest of the Mary-Polk County deposit, the School Property and Cherokee orebody has an outcrop more than a mile in length, the strike of which is approximately North 30° East and the dip to the southeast 65°. Several shafts have been sunk into the sulphides and many holes drilled to determine the grade of the ore of the School Property, which is principally pyrrhotite with pyrite and a little chalcopyrite. At one part of the deposit, however, pyrite is the predominant mineral. No prospecting has been done on the Cherokee part of the deposit, but the ore is probably similar to that found on the School Property. The sulphur content in general is about 30 per cent., though it is quite possible that a considerable quantity of 40 per cent. ore could be mined. The copper content is a little over 1 per cent. The length of the deposit being over a mile, and the width varying to a maximum of 100 ft., there are undoubtedly many million tons of ore here.

Across the State line, in Georgia, about 2 miles southwest of the School Property and Cherokee deposit, is the Number Twenty mine, whose present workings extend northeast and southwest for a distance of 1000 ft. The sulphur is about 20 per cent. and the copper about 2 per cent. The mine is in operation and may produce as much as a million tons of ore, or even more.

Farther to the southwest is the now abandoned Mobile mine. Very little is known of the deposit, but an examination of the dumps near the old shaft indicates that the ore is very low in sulphur.

The London and Burra Burra mines are owned and operated, and the Polk County mine is leased and operated, by the Tennessee Copper Co. The smelter at Copperhill smelts the ore from the Number Twenty Min-

ing Co. as well as from there. During 1916, the Tennessee Copper Co. completed the erection of a large new sulphuric acid plant, which, together with the plant formerly built, utilizing the gases from the smelter, will produce annually 250,000 tons of sulphuric acid having a strength of 60° Bé.

The East Tennessee and Mary mines are owned and operated by the Ducktown Sulphur, Copper, & Iron Co., Ltd. The ore produced is treated at its smelter at Isabella, and the gases converted in a sulphuric acid plant which has an annual capacity of nearly 50,000 tons of 60° acid.

There remains available as a source of sulphide ore, but now being utilized, the Isabella-Eureka deposit and also the School Property and Cherokee deposits. The ores of the other mines are all being utilized at present and are necessary to continue the operations of the smelters, with their byproduct acid plants. The Isabella part of the deposit, above mentioned, has produced a small amount of ore for smelting and for experimental purposes. During the experiments, the ore was crushed and roasted in a Wright roaster, the gas being used in the acid plant, with excellent results. The following analysis is typical of the comparatively small amount of ore from this mine that was treated: Sulphur, 31.84 per cent.; iron, 40.80 per cent.; copper, 0.98 per cent.; silica, 11.08 per cent.; CaO, 4.32 per cent.; MgO, 3.67 per cent.; Al_2O_3, 0.98 per cent.; zinc, 0.97 per cent. The mine is owned by the Ducktown Sulphur, Copper, & Iron Co., Ltd., and could in a few weeks be put on a production basis of 200 or more tons per day. The Ducktown company has blocked out in this deposit over 2,500,000 tons of ore averaging 29 per cent. sulphur and 0.8 per cent. copper. A small amount of mining has been in progress for some years and the property could quickly be developed to an output of several hundred tons a day of better than average grade ore.

The Tennessee Copper Co. has available the Eureka part of the above deposit, where diamond drilling has indicated that there are about 2,000,000 tons of pyrrhotite and pyrite intimately associated, that averages 29 per cent. sulphur. After several months for development, there can be mined 200 tons per day.

The remaining available deposit, the School Property, now leased by W. Y. Westervelt for a term of years, is undergoing a thorough testing by diamond-drilling. The drilling done thus far leaves no doubt as to the presence of a large mass of ore of which the following is a typical assay: Sulphur, 32.65 per cent.; iron, 49.05 per cent.; copper, 1.05 per cent.; zinc, 0.08 per cent.; silica, 6.40 per cent. Six months would suffice to develop the property to the point where 200 tons of ore could be mined daily, and ultimately 1000 tons per day might be mined. In addition to the above ore, in which pyrrhotite predominates, two diamond-drill holes have encountered massive pyrite of which the following is an assay: sulphur, 42.01 per cent.; iron, 42.98 per cent.; copper, 0.27 per cent.; silica,

5.15 per cent. zinc, 1.60 per cent. It is hoped that further drilling will prove several hundred thousand tons of this higher grade of ore. As the ore lies within a few hundred feet of the surface, it should be possible to sink a shaft, develop the deposit and be producing 1 to 300 tons of ore per day inside of 6 months' time.

In brief, there are in the Ducktown district three properties partly developed that give every indication of being able to supply 500 to 1000 tons of ore daily for a generation to come. These ores can be made available in from a few weeks to a year's time. The sulphur content would in general be 30 per cent., in the form of pyrrhotite and pyrite intimately associated. In addition, there is a lesser amount of pyrite, averaging 40 per cent. sulphur, that can be made available in 6 months' time.

Ore Deposits of the Yellow Pine Mining District, Clark County, Nevada

BY FRED A. HALE, JR.,* B. S., GOODSPRINGS, NEV.

(New York Meeting, February, 1918)

1. Introduction

Owing to the large area included in the Yellow Pine mining district, and the varied nature of its mineral deposits, a detailed geological description of the district could be covered only in an extensive monograph. This paper is intended as a description of the most prominent geologic features only with special reference to those of economic importance.

The first mention of the district was in 1903 by J. E. Spurr,[1] who briefly describes the structural geology of the Spring Mountain range. In 1906, H. F. Bain[2] briefly described the Potosi mine. James J. Hill,[3] of the United States Geological Survey, visited the district for a brief period in 1912, the result of which is an excellent reconnaissance report, covering the district in some detail but necessarily with brevity. Since that time, articles covering special features of the district have appeared in the technical press, including some by the writer, and a notable description of the Boss mine, by Adolph Knopf,[4] appeared in 1915.

Development of the district during the past few years has progressed so rapidly and with so many notable discoveries, particularly with reference to the rare metals, that a further description at this time may prove of interest. The writer's acquaintance with the district is based on 7 years' continuous residence in the vicinity, beginning with the spring of 1910.

A. Location and Topography

The Yellow Pine mining district is situated in the southwestern portion of Clark County, Nevada, about 300 miles northeast of Los Angeles, along the line of the Los Angeles & Salt Lake Railroad. The district extends from Mt. Olcott on the north to the California line on the south,

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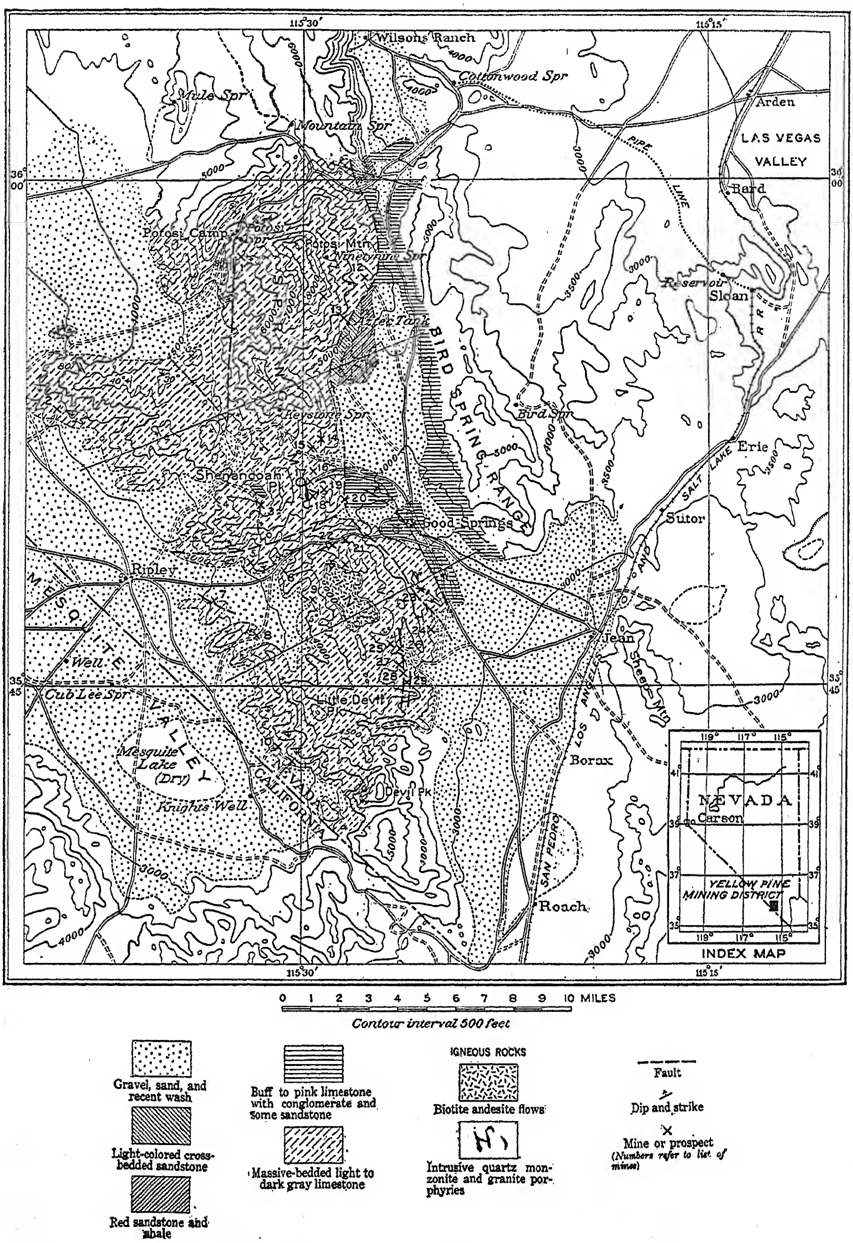
* General Manager, Yellow Pine Mining Co.

[1] Geology of Nevada South of the Fortieth Parallel, *Bulletin* 208, U. S. G. S.

[2] *Bulletin* 285, U. S. G. S.

[3] *Bulletin* 540F, U. S. G. S.

[4] *Bulletin* 620A, U. S. G. S.



1. Potosi
2. Green Monster
3. Keystone
4. Aura Amigo
5. Whale
6. Bill Nye
7. Hoodoo
8. Springer and Tiffen
9. Hoosier
10. Milford
11. Addison
12. Ninety-nine
13. Contact
14. Ninety-three group
15. Red Cloud
16. Prairie Flower
17. Yellow Pine
18. Alice
19. Porphyry Canyon
20. Lavinia
21. Columbia
22. Frederickson
23 Monarch
24 Lincoln
25. Porter
26. Monte Cristo
27. Accident
28. Bonanza
29. Anchor

FIG. 1.—SKETCH MAP OF THE YELLOW PINE MINING DISTRICT, CLARK COUNTY, NEV. (*After James M. Hill, U. S. G. S. Bulletin No. 540, Plate I.*)

with a width of about 16 miles east and west, the total comprising an area of approximately 400 sq. miles. The principal shipping point of the district is Jean, Nev., on the Los Angeles & Salt Lake Railroad, although considerable ore is also shipped from Arden and Roach, other points on the same railroad. A narrow-gage railroad, owned and operated by the Yellow Pine Mining Company, but used exclusively for ore haulage, connects Jean with Goodsprings, 8 miles west of the railroad, and thence proceeds to the Yellow pine mine, 4 miles further west. Goodsprings is situated at about the center of the district, and is the main source of supplies. Wagon roads connecting the various properties with the railroad are uniformly good during all seasons.

The Yellow Pine district embraces the south end of the Spring Mountain range, an extremely irregular group of mountains composed

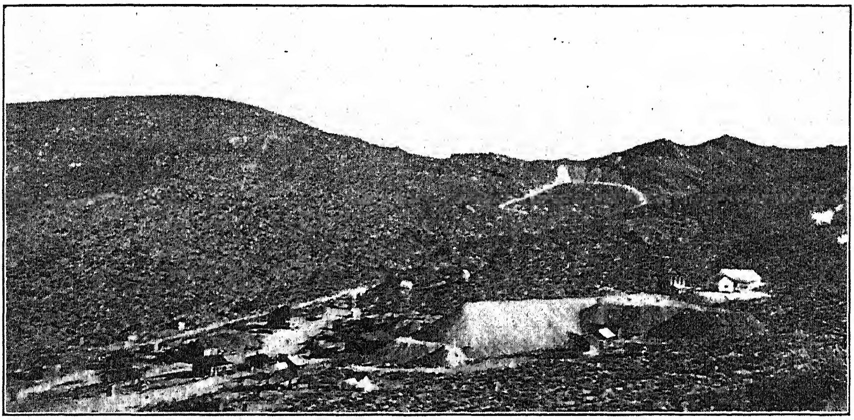


FIG. 2.—YELLOW PINE MINE AND CAMP.

largely of sedimentaries. The range is separated from the Kingston Mountains on the west by the Mesquite valley, with Ivanpah valley immediately east of the range. These are both broad flat valleys greatly accentuating the rugged character of the adjacent mountains. The general trend of the Spring Mountain range is northeast and southwest, the highest point being Mt. Olcott on the north, having an elevation of 8500 ft. (2591 m.), with Diablo Grande on the extreme south, with an elevation of 5865 ft.

Water is not abundant in the district, but a few natural springs occur on the slopes of Mt. Olcott and an abundant water supply has been developed at Goodsprings by wells of shallow depth. Water has also been developed in considerable quantity at various points in the Mesquite valley. An equable climate makes operation possible throughout the district at all times of the year.

B. History and Production

The oldest mine in the district, and one of the first locations in Nevada, is the Potosi, situated on the west slope of Mt. Olcott, adjacent to the old Mormon trail, which connected Salt Lake City with San Bernadino. It is said that this mine was discovered by Mormons as early as 1852, and lead ore from the outcrop was smelted, after a crude fashion, for molding into bullets. However, owing to the inaccessibility of the district, it attracted little attention until after the discovery of gold at the Keystone mine in the early nineties. The Keystone mine, situated on the west slope of the range, produced some very rich gold ore, and is credited with a production of over $1,000,000, most of which was milled at a small plant erected at Sandy, in the Mesquite valley. The discovery of this mine stimulated prospecting in the district with the result that many locations on outcrops of copper, lead, and silver were made. It was not until 1906 that the presence of zinc was recognized in the ore, and the advent of the Los Angeles & Salt Lake Railroad about that date resulted in increased shipments from the district.

However, the complex nature of the mixed lead-zinc oxidized ores presented many difficulties, and first results from the smelters were somewhat disappointing to the shippers. After considerable experimenting, in 1910 the Yellow Pine Mining Co. evolved a process for separating the lead and zinc minerals in their ores to produce readily marketable products, with the result that a 100-ton plant was erected at Goodsprings and has been operated successfully since that date. The Yellow Pine narrow gage railroad was constructed in 1911, resulting in greatly improved transportation facilities. During recent years, several smaller milling plants have been erected, most of them of the dry concentration type, and production of the district has steadily increased.

An important development of recent years was the discovery in 1914 of platinum metals in the ores of the Boss mine. This discovery attracted considerable attention to the district and some valuable development has been accomplished; the production of platinum promises to become of prime importance to the district.

The production of the Yellow Pine mining district, up to and including 1915, is as follows:[5]

Year	Gold	Silver, Oz.	Copper, Lb.	Lead, Lb.	Zinc, Lb.	Total Value
To 1912	$196,515	101,779	521,411	5,138,247	15,834,643	$1,453,715
1912	34	223,013	103,398	6,544,917	13,254,860	1,363,354
1913	1,268	192,339	283,592	6,204,065	14,369,709	1,239,081
1914	8,034	122,703	156,389	4,185,208	11,862,149	864,882
1915	833	100,146	262,600	4,620,243	21,061,182	2,926,300
Total....	$206,684	739,980	1,327,390	26,692,680	76,382,543	$7,847,332

[5] Taken from *Mineral Resources of the United States.*

These figures include only the production reported to the United States Geological Survey and necessarily do not include the entire production of the district; the gold production of the Keystone mine is, for example, absent. Production figures for 1916 are not yet available, but will show a substantial increase in all metals over 1915. It may, therefore, safely be stated that production of the district to date is in excess of $12,000,000.

2. Areal Geology

A. Sedimentary Rocks

The Spring Mountain range consists largely of sedimentary rocks of Paleozoic age, estimated by Spurr to have a total thickness of approximately 17,000 ft. (5181 m.). Of this section, about 2000 ft. (609 m.) is Cambrian quartzite, exposed at the extreme north end of the range, the rest being limestone of Cambrian and Carboniferous age. Devonian limestone may also be present in the series, but, if so, it has never been definitely identified. At the north end of the range, the east flank is composed of a series of 1500 ft. of yellowish and reddish sandstone of Mesozoic age, correlative to the Triassic and Jurassic of the Grand Cañon series. Flanking the range to the south is a series of Quaternary gravels more or less consolidated.

From an economic standpoint, the important part of the section is a series of Carboniferous sedimentaries, about 3000 ft. in thickness, comprising the main portion of the southern limb of the Spring Mountains, as it is in this series that all known orebodies in the Yellow Pine district have occurred. The series is composed mainly of limestone, varying in appearance from light-colored thinly bedded strata, to massive, dark thick-bedded limestone. Most of the limestone is somewhat siliceous, although occasional strata are composed of a pure crystalline variety somewhat marbleized, and dolomitic varieties are not infrequent. The limestone beds are occasionally interspersed with strata of a grayish fine-grained sandstone, important only on account of their relation to known orebodies, and some beds of calcareous shale are also evident.

Fossils are not plentiful in this series, but varieties of *Zaphrentis*, *Spirifer* and crinoidal fragments have occasionally been noted. An identification of fossils made by G. H. Girty, and included in Mr. Hill's report, seems to indicate that the ore-bearing measures are Upper Mississippian. Lower Pennsylvanian has also been identified in the series, but is not of much importance.

B. Igneous Rocks

Igneous rocks are not plentiful in the Yellow Pine district but are important on account of their relation to known orebodies. The intrusive

rocks consist largely of dykes and sills of monzonite-porphyry, varying in color from pink to yellowish brown. The most prominent intrusions consist of three large dykes of monzonite, striking nearly north and south, roughly parallel and with several hundred feet of sedimentaries intervening. These dykes are known respectively as the Lavina, Yellow Pine, and Keystone porphyries, and outcrop at various points in the district, indicating a thickness of from 100 to 400 ft. (30 to 121 m.). The rock composing the dykes varies greatly in texture, but in all cases is distinctly porphyritic, showing phenocrysts of quartz, orthoclase, plagioclase, biotite, and augite, in a fine-grained groundmass. Some sections of the porphyry indicate considerable alteration, such minerals as limonite, chlorite, and sericite being present, but the sedimentaries in contact with the intrusions show very little alteration.

In addition to the three larger intrusions are numerous smaller dykes, usually striking about N. 30° W. and varying in thickness from 10 to 20 ft. (3 to 6 m.). The rock of these dykes is a monzonite-porphyry, similar to that described above except that it appears to be slightly more acid, and the dykes frequently occur associated with the larger intrusions. It is possible in some cases that the smaller dykes are offshoots from the large intrusion, although the writer is of the opinion that they are due to a phase of minor intrusion following the original intrusive period. The age of these intrusions has not been definitely established, but it is undoubtedly post-Jurassic and probably Tertiary. The only occurrence of extrusive rock in the district is a horizontal sheet of biotite-andesite, about 20 ft. thick, capping what is known as Table mountain, in the southern part of the district. This is evidently of volcanic origin and has no relation to ore deposits.

C. Structure

The Spring Mountain range throughout shows intense and complex folding, accompanied by numerous faults and fissures. According to Spurr, the general structure of the range is a broad syncline with numerous minor folds. Across the north-south section the structure is anticlinal. However, in the Yellow Pine mining district, the sedimentary beds have a persistent dip westerly or southwesterly at angles of 15 to 45° and may be considered monoclinal. In the vicinity of Porphyry Gulch, in which is the Yellow Pine mine, is a local dome-shaped anticline, with a central axis about at the apex of Ruth mountain. The northern limb of this anticline has been removed by erosion, but the southern limb includes the ore zones of the Yellow Pine, Yellow Pine Extension, and Prairie Flower mines. At the Yellow Pine Extension, on the south, the beds dip southerly, westerly at the Yellow Pine, and northwesterly at the Prairie Flower, the strike of the beds assuming roughly the arc of a circle. Other local folds occur at various points in the district, notably

in Devil Canyon near the south end of the district, where intense local folding is evident.

Of the faults observed in the district, by far the most profound is the Great Fault along the eastern slope of the Spring Mountain range. This is evidently one of the main continental faults, striking nearly north and dipping steeply in an easterly direction. The throw of the fault is evidently at least 3000 ft., the eastern block being down-thrown this distance, as evidenced on the eastern slope of Potosi mountain, where the Mesozoic sandstone is against the Mississippian limestone. This fault may be readily traced throughout the length of the district, a distance of 25 miles.

Two other important series of faults occur in the district; a series striking about N. 30° W., dipping 75° northeasterly and a series striking north and south, parallel with the Great Fault, but with minor throws. One or both of these series of faults are invariably associated with the orebodies and on this account are of special importance.

3. Ore Deposits

The principal ore deposits of the Yellow Pine district may be divided into two general classes, oxidized lead-zinc deposits, and copper-gold deposits; some of the latter also contain an important proportion of platinum metals. Of the two classes, by far the greater tonnage has been derived from the lead-zinc deposits, although of late years the copper-gold deposits have assumed considerable importance. Silver in varying quantities is contained in ores of both classes and is an important constituent of nearly every deposit.

A. Oxidized Lead-zinc Deposits

Ore deposits of this class occur in three distinct stratigraphic zones throughout the district, nearly every orebody having certain characteristics from which its zone may be determined. On account of the intense folding and faulting in the district, an exact correlation of the various ore deposits would involve considerable labor, but an approximate classification is as follows:

1. Lower zone, including the Potosi, Snowstorm, Contact(?), Pilgrim, Prairie Flower, Yellow Pine, and Yellow Pine Extension, with possibly the Monte Christo orebodies.
2. Middle zone, including the Mobile, Whale, Lookout, Mountain Top, Palace, Porter, Accident, Bullion, Anchor, and Valentine orebodies.
3. Upper zone, including the Bill Nye, Akron, Surprise, Dividend, Volcano, Christmas, and New Year orebodies.

Such properties as the Green Monster, Milford, Addison, and Tam

O'Shanter have not been included in the classification, as their distance from other deposits makes correlation difficult without a careful study of the individual property. However, it is possible that they may be included in one of the known zones.

The distances between the various zones have not been computed accurately, but amount to several hundred feet, the greater distance being between the lower and middle zones, and all zones being included in the Upper Mississippian limestone series.

Of the lower zone, which to date has been the most productive in the district, the Yellow Pine mine in Porphyry Gulch may be taken as the best example, this property having a larger record of production than any in the district, and the nature of the deposit being typical of the oxidized lead-zinc orebodies in the vicinity.

The deposit at the Yellow Pine mine occurs adjacent to, but not in contact with, a large intrusion of monzonite-porphyry, previously mentioned as the Yellow Pine porphyry. The intrusion in the vicinity of the Yellow Pine takes the form of a sill, the contacts being conformable with the limestone strata, which dip about 35° westerly. A generalized section in this vicinity is as follows:

Intrusive......	400 ft.	Monzonite-porphyry
Mississippian...	0–100 ft.	Dense gray thick-bedded limestone
	40 ft.	Calcareous sandstone
	30– 60 ft.	Crystalline limestone (ore zone)
	0– 60 ft.	Dense gray dolomitic limestone
	30 ft.	Thick-bedded calcareous shale

For exploration purposes, the index strata are considered to be the calcareous sandstone in the hanging wall and the thick-bedded shale in the foot-wall of the so-called "ore zone." These beds are evident in all deposits of the lower zone, except where they have been removed by erosion, as is the case at the Potosi mine, where the sandstone is absent. In the Yellow Pine mine, the orebodies frequently extend to one or the other of these index strata, although more often there are beds of intervening limestone, and in no case does the ore extend into or beyond either the sandstone or the shale.

The orebodies of the Yellow Pine are essentially of the replacement type, and are apparently confined to one limestone stratum, although frequent step-faulting with considerable throw gives the appearance of separate orebodies. The step-faults are of the N. 30° W. series, with the southern block invariably thrown northwesterly, and have evidently been the means of egress for the mineral-bearing solutions which formed the replacement deposits. In fact, the large continuous orebodies which are found in the Yellow Pine mine are apparently due to the frequent occurrence of faults of this nature, it being apparent that the mineral-bearing solutions were incapable of replacing the limestone more than

a few feet from a zone of fracture. Most of the northwest faults are mineral-bearing in the nature of a fissure filling, and much valuable ore has been derived from this source, although the greater quantity by far has come from the replacement beds.

The ores of the Yellow Pine mine consist of a mixture of smithsonite and calamine, with cerussite and occasional galena, the lead minerals carrying silver values to the extent of about 0.5 oz. to the per cent. of lead. Hydrozincite in irregular masses and cave-fillings is commonly found in the orebody, and anglesite is a not infrequent mineral. The ore is commonly of brownish or pinkish color, due to the presence of small quantities of iron, cobalt, and manganese, and varies in texture from earthy masses to dense hard chert-like varieties. The lead and zinc minerals are intimately mixed as a rule, although considerable zinc ore, free from lead, has been produced, and some high-grade lead ore comparatively free from zinc. A general average of the metal content of all ores extracted to date (approximately 100,000 tons) would be about 30 per cent. zinc, 14 per cent. lead, and 9 oz. silver per ton.

There are no true gangue minerals in the Yellow Pine deposit, the entire limestone stratum having been replaced by the lead and zinc minerals in most cases, except for occasional narrow ribs of siliceous limestone, frequently altered to chert, in irregular masses in the orebody. Small masses of soft limonite, calc-spar and gypsum have also been noted, these being the result of alteration of the original orebody.

The orebodies of the Bybee mine have been of remarkably large size, considering the high metal content of the ore. At a depth of 100 ft. (30 m.), the length of the main orebody was 360 ft. with an average width of 40 ft. This was followed continuously to a depth of 500 ft., the limits being more or less irregular. Both north and south, the ore was cut off by northwest faults, but at a depth below the 500-ft. level, a southern extension of the orebody was discovered and has been stoped 300 ft. south and 200 ft. in depth, with limits as yet undetermined. Similarly, a northern extension of the orebody has recently been developed nearly to a depth of 700 ft. The width of the orebody remains fairly uniform throughout both north and south extensions.

At a point below the 700-ft. level, a brecciated limestone zone occurs, evidently due to a north-south fracture, and of a later occurrence than the ore deposition, resulting in a considerable displacement of the ore zone. Some prospecting beyond the brecciated zone has been in progress, resulting in the discovery of small orebodies, but as yet the main ore zone has not been found.

A remarkable feature of the Yellow Pine mine is that the orebody at depth appears to be as thoroughly oxidized as close to the surface, no sulphide of zinc having been found and no increase in the amount of lead sulphide. This is undoubtedly due to the intense faulting and

fracturing throughout the orebody, allowing free access of oxidizing agents to considerable depths. No ground-water level has yet been reached, nor are there any indications of the proximity of water, even at a depth of 950 ft.

In some adjacent properties, notably the Yellow Pine Extension and Potosi, some sulphide ore was found within a few hundred feet of the surface, but in every case it is encased in a dense hard matrix of oxidized ore. This sulphide ore is of special interest in that it is indicative of the original character of the ore.

The Yellow Pine orebody presents an excellent example of zonal secondary enrichment of the three principal constituents of the ore, lead, zinc, and silver. Although the total metal content of combined lead and zinc remains practically constant throughout the orebody, the proportion of lead to zinc is considerably greater near the surface than at depth, with a gradual diminution of lead and consequent increase of zinc content in depth. This is apparently due to the greater solubility of the zinc minerals, resulting in a farther migration from the original source, while the lead minerals were deposited to greater extent at shallower depths. The silver content of the ore shows a marked increase with depth for a distance of 120 ft., from which point it decreases to a minimum at a depth of 700 ft.

Of other properties classified as in the lower zone, the Potosi mine, situated in the north end of the district, is of next importance, having produced approximately 60,000 tons of oxidized ore during the past few years. The ore is similar in character to that of the Yellow Pine, except that the lead content is considerably less and practically all the shipments have been of crude zinc ore. The deposit at the Potosi is very similar to that of the Yellow Pine, the same northwest fractures appearing prominently, but owing to the nearly horizontal nature of the sedimentary beds in that vicinity, the ore deposits assume the same dip, and are worked through adits. The smaller content of lead in the ore, as well as the presence of zinc sulphide in some parts of the orebody, appears to indicate that the upper extent of the orebodies, corresponding to the higher lead-bearing levels of the Yellow Pine, has been removed by erosion, as is indicated also by the topography. Ore deposits in the Yellow Pine Extension and Prairie Flower, other properties in the lower zone, are similar in character to those of the Yellow Pine, although somewhat smaller, and the Pilgrim and Snowstorm properties show similar characteristics.

The ore deposits classified as in the middle zone all occur in a buff-gray crystalline limestone stratum which strikes nearly north and south and dips westerly at angles from 15° to 45°. This stratum may be traced continuously throughout the district, although it is frequently displaced by faults. A bed of heavy blue limestone, showing nodules of

chert which are apparently silicified forms of *Zaphrentis* corals, immediately overlies the ore-bearing limestone of the middle zone, and forms a distinctive stratum from which the various orebodies may be correlated. The orebodies are by no means continuous throughout the length of the bed, a distance of some 8 miles, but seem to be entirely dependent upon local faulting and fissuring at various points along its extent. Igneous intrusions have apparently not been of so much importance to ore deposition in this zone, although the relation of igneous activity to the deposition has not been clearly demonstrated.

The ore found in this zone is somewhat similar to that of the lower zone in that the principal constituents are minerals of lead, zinc and silver. However, the ore generally is not so thoroughly oxidized and presents some distinctive characteristics. The lead occurs mostly as galena, occasionally coated with anglesite and showing some cerussite. Silver content usually averages about 0.25 oz. to the per cent. of lead. Zinc occurs almost entirely in the form of carbonate, varying from a soft pinkish variety to hard crystalline smithsonite. Sphalerite has also been noted in several instances, encased by hard smithsonite. Gangue minerals are much more frequent than in the lower zone, a crystalline calc spar being characteristic of the zone. Large masses of soft limonite and granular quartz are sometimes present.

Of the properties in the middle zone, the Anchor, situated in the southeastern portion of the district, has had the largest production and is a typical deposit. The property has been developed to a depth of about 400 ft. (121 m.) showing frequent ore-shoots averaging about 4 ft. thick and of varying lateral extent up to 100 ft., the length evidently being governed by the distance from fault fissures. The ore frequently occurs as a mixed lead-zinc mass, which must be separated by milling, but there are also large bodies of lead ore almost free from zinc, and some crude zinc ore has been produced. Properties similar to the Anchor, but having less development are the Valentine, Bullion, Accident, Porter, and Mountain Top, all of which have produced lead and zinc ores in varying amount. At the Whale mine, located on the northwest extremity of the ore stratum, lead is largely absent, the mixed lead-zinc zone having evidently been removed by erosion, and the ore is largely carbonate of zinc in a crushed calcite gangue.

The so-called upper zone is less developed than either of the lower zones but in recent years has become of considerable importance, and is found in the Bill Nye, Surprise, Dividend, and Christmas properties. The ore at all of these properties presents a more siliceous facies than either of the other two zones, the ore occurring adjacent to and occasionally included in, a bed of grayish fine-grained sandstone. The underlying stratum is a soft crystalline limestone, also ore-bearing, and the footwall is a heavy blue dolomitic limestone. As in the lower zones, fissuring

seems to have played an important part in the ore deposition, and both the northwest and north-south fracturings are quite prominent. In the ore, lead occurs largely as galena, showing marked flow-structure, the cubic variety not occurring in large quantities. The silver content is considerably higher than in either of the other zones, averaging about 0.75 oz. to the per cent. of lead and frequently much higher. Zinc occurs largely as calamine, but smithsonite and hydrozincite are usually present.

The Root Bonanza and Sultan properties, important producers during recent years, are situated in the extreme western portion of the district, and owing to the extensive faulting in the vicinity, are difficult to correlate with other ore zones. In both properties, the ore consists of zinc carbonate and silicate, with galena and some oxidized lead ore. Zinc minerals apparently predominate, but the lead ores, carrying an unusually high content of silver, indicate correlation with the upper zone. However, the proof is not conclusive, and it appears more probable that these ore deposits occupy a higher stratigraphic horizon in the series than those previously described.

B. Copper-gold Deposits

The copper-gold deposits are found in various localities in the Yellow Pine district, apparently without any stratigraphic relation to the zinc-lead deposits. They are usually clearly distinct from the lead-zinc orebodies, but similarly, they are apparently determined by the presence of fracture zones, usually of the northwest series. It is also significant that they are usually found in the vicinity of intrusives; in fact, at the Lavina mine, a large monzonite-porphyry intrusion contains pyrite and chalcopyrite in considerable quantity, clearly indicating that the intrusives have been the source of the copper ore in the vicinity.

The Lavina intrusive contains the only primary ore yet discovered in the district, other orebodies consisting largely of minerals typical of the zone of oxidation; cuprite, malachite, azurite and chrysocolla, with occasional chalcocite.

At the Ninety-nine, Copper Peak, and Columbia properties, all of which have records of substantial copper production, the ore occurs in a buff-colored crystalline limestone, in masses roughly conformable with the strata and averaging a few feet in thickness. Minerals of the orebodies are all of the secondary type, cuprite and malachite predominating, with occasional chrysocolla and chalcocite. Apparently, the orebodies are all of the replacement type, with lateral extent limited by the distance from fractures. Replacement of the limestone beds has not been complete in most cases, the common gangue minerals in the ore being a pinkish calcite and soft limonite. The orebodies in these properties are

not definitely associated with igneous intrusions but the fact that they occur in a belt of igneous activity seems to indicate that further development will disclose their relation to igneous rocks.

At the Lincoln property, situated in the eastern portion of the district, ore of similar character occurs in limestone adjacent to a large intrusion of monzonite-porphyry. This deposit is of special interest in that the oxidized ore is associated with cerargyrite (horn silver) which occurs in considerable quantity in the cleavage planes of the ore, which is a mixture of cuprite and malachite. Gold is also present to some extent.

The central western portion of the district has assumed considerable importance of late years on account of the discovery of platinum metals associated with the copper ores in this vicinity. Of the orebodies so far discovered, the largest and most important is that at the Boss mine, where ore of unusually high grade and in considerable quantity has been exposed. The ore occurs in a series of dolomitic limestones, part of the Upper Mississippian series, striking northeast and dipping about 15° west. All orebodies so far developed occur in a zone of fracture, striking north and averaging about 30 ft. in width. About 500 ft. north of the deposit is a large intrusion of monzonite-porphyry, probably an extension of the Keystone porphyry. Some development work on the contacts of this porphyry have shown low gold content, but generally it appears unmineralized.

The Boss mine has been opened by a series of four adits, following the fractured zone at various elevations. All of these expose ore shoots, the largest opened to date being between the first and second levels, where an ore zone averaging about 12 ft. (3.6 m.) thick and 150 ft. (45.7 m.) long, has been disclosed. Two types of ore occur in this orebody, a light-gray quartzose material that crumbles to a fine sand, which contains platinum and gold almost entirely free from copper, and a copper ore, containing malachite, chrysocolla, and cuprite, occasionally associated with limonite. The oxidized copper ore usually contains very little platinum or palladium when free from the quartzose material. Knopf has determined that the gray sandy material consists of perfectly formed crystals of quartz, about 0.1 mm. in diameter, containing also fine grains of octahedrite (titanium oxide) and rutile.

Associated with the quartzose material in the form of irregular masses and small veinlets is a greenish talcose substance which has been identified as a bismuthic variety of plumbo-jarosite, a basic lead ferric sulphate. A careful study of this mineral has demonstrated beyond doubt that it contains the gold and platinum in the Boss ore to a very large extent. Apparently, however, neither the gold nor platinum is in combination chemically with this mineral, but occurs in the free metallic state intimately associated with it. By crushing and panning this material, fine grains of a blackish substance are obtained, which,

upon cleaning mechanically or with acid, discloses itself as gold of a normal yellow color. Only very rarely can a grain of the platinum metals be panned, as it is evidently so finely divided as to resist mechanical concentration. Analyses of the gold, however, have demonstrated beyond doubt that the gold and platinum occur separately and not as an alloy, nor have any minerals of platinum other than the native metal been identified.

The metals of the platinum group found in this ore are platinum, palladium, and iridium, with traces of rhodium. Only platinum and palladium occur in sufficient quantity to be of commercial value, and the two are found in apparently no fixed ratio. Generally, however, palladium exceeds the platinum content, although a sample of a small shipment of high-grade ore, made in 1914, assayed 111 oz. gold, 99 oz. platinum and 16 oz. palladium to the ton. Other samples of the plumbo-jarosite have assayed approximately 500 oz. gold and 260 oz. platinum metals per ton, the platinum metals containing palladium in excess of platinum. According to Knopf, a composite of 22 samples taken in the orebody, and including the quartzose gangue matter with streaks of plumbo-jarosite, assayed 3.46 oz. gold, 6.4 oz. silver, 0.7 oz. platinum and 3.38 oz. palladium per ton, which may be considered as an average of the high-grade siliceous ore in the mine.

The copper ore is usually quite distinct from the siliceous material; occurring as a casing and immediately underlying the siliceous deposits, also as veins 2 to 4 ft. thick following fractures; and as irregular cave-fillings on the footwall of the fractured zone. This ore contains gold and platinum metals only in limited quantities, the pure cuprite and malachite containing practically no precious metal. However, immediately underlying the large body of siliceous ore is a deposit averaging some 12 ft. thick, composed almost entirely of chalcocite in a fine-grained siliceous gangue of unusual hardness. Average samples of this ore indicate a content of about 15 per cent. copper, 0.8 oz. gold and 0.5 oz. platinum per ton. No primary ore has as yet been encountered in the mine, although development work is being done at depth. Large bodies of thoroughly leached zones showing much limonite with occasional veinlets of copper carbonate, disclosed on the upper levels, seems to indicate that a further zone of secondary enrichment may be expected with further depth.

At the Oro Amigo property, three miles north of the Boss, similar ore in smaller quantities has been discovered, and prospecting is being actively prosecuted. Copper ore containing small quantities of gold and platinum metals have also been reported from the Scottish Chief and Platino properties. Apparently all of these properties are located on the same zone of fracture as the Boss and include similar geologic conditions. North of the Oro Amigo is the Keystone mine, which has

produced considerable gold ore, occurring as a quartzose deposit on the contact of monzonite-porphyry and limestone. Apparently, the monzonite is an extension of the large intrusion noted in the vicinity of the Boss. West of this intrusion is a zone including the Ironsides, Azurite, and Copper Chief properties, all of which have produced considerable oxidized copper ore, but without any platinum content, the ore occurring as irregular masses in limestone.

C. Genesis of the Ore

It has been noted that all the orebodies of the Yellow Pine mining district are essentially of the replacement type, with occasional fissure-filling in the fractures that apparently served as a means of egress for the mineral-bearing solutions. From the character of the minerals found in the various deposits it seems certain that both the zinc-lead and copper-gold ores originated from ascending mineral-bearing solutions, probably at high temperature, closely following intrusions of the monzonite-porphyry magmas. The relative time of deposition of these two ores is of course problematical. The writer is of the opinion that the copper-gold ores were deposited first, following closely after the intrusion of the large monzonite-porphyry magmas described as the Lavina, Keystone, and Yellow Pine dykes. At a subsequent period, as a phase of the minor intrusions which usually follow intense intrusive action, the magmas which constitute the smaller dykes were intruded, accompanied by the solutions which subsequently formed the lead-zinc deposits. That the smaller dykes were intruded subsequent to the larger intrusions can be clearly determined from their structural relations, and the relative positions of the various deposits with reference to intrusives seems to indicate genetic relations as stated. In only one or two instances are the copper-gold and zinc-lead ores found in the same deposit, and where this is the case, the deposit is invariably in close proximity to intrusions of both types, indicating that the deposition may have occurred at two distinct periods, also evidenced by the general character of the ore.

The primary ore of the lead-zinc deposits was undoubtedly in the sulphide form, consisting largely of sphalerite with some argentiferous galena and pyrite. Primary ore of this character is found at the Potosi mine and in small quantities at other properties. This sulphide ore replaced certain favorable limestone beds by the action of hot ascending waters originating with the igneous magma. Apparently, the replacement was complete or nearly so, although in some instances, the sulphides were associated with a calcite gangue. At a subsequent period, this ore was evidently brought into the zone above water-level and subjected to the action of ordinary oxidizing agents, with the result that the sulphide forms were changed to the various oxidized forms of lead and zinc.

This process was probably brought about by the oxidation of sulphide to sulphate, which reacted with the limestone to form carbonates of lead and zinc, with the formation of calcium sulphate. The latter, gypsum, is a frequent gangue mineral in all the ores, and some lead sulphate is also present. Limonite in the ore is due to the oxidation of iron sulphides which probably accompanied the lead and zinc sulphides. In the processes of oxidation there was undoubtedly some migration of the metals, particularly in the case of the lead and silver, but it seems probable that most of the zinc carbonate ore was altered in place, with little or no migration except in the case of hydrozincite, which in some instances has been carried a considerable distance from its original source.

The limestone which seems to have been the most amenable to replacement by the mineral-bearing solutions is a grayish pure crystalline limestone. It has been the theory that dolomitic limestones were especially favorable, but apparently this is not the case, as the magnesia content appears to have had little influence on the deposition. It is quite evident that two conditions were essential for ore deposition, a fractured zone, which may be assumed to have led from an igneous magma, and a limestone favorable to replacement by the ascending solutions, conditions which exist in all orebodies discovered to date.

The deposition of the copper-gold ore undoubtedly occurred similarly to that of the lead-zinc deposits, except that the ascending thermal waters originated in the earlier magma. The ore originally contained copper in sulphide form, accompanied by considerable iron sulphide as evidenced by the presence of large quantities of limonite in the present oxidized ore. Complete oxidation has resulted in concentration of the precious metals that were originally contained in the primary ore. In the case of the Boss mine, plumbo-jarosite seems to have been an especially active precipitant for gold and platinum. Apparently, descending ground-waters oxidized the original copper-iron sulphides, with the formation of ferric sulphate, which subsequently reacted with galena to form plumbo-jarosite. Later solutions, containing small quantities of gold and platinum, found this mineral an active precipitant, with resultant concentration of precious metal. Owing to the absence of any primary ore in the Boss, it is difficult to determine the metal content of the original ore, but it seems evident that the chalcocite ore has been altered in place with little migration of metallic content and practically no enrichment, so that it may be assumed as characteristic of the original metal content. The copper carbonate ore is evidently the result of deposition from solutions which have carried the copper considerable distances from its original source, and there are many instances in the Boss mine where large leached zones indicate that the valuable metals have been removed, the corresponding re-deposits not having been as yet discovered.

IV. Concentration and Extraction Methods

It will be noted that development of the properties in the Yellow Pine mining district to date have been comparatively meager. With the exception of the Yellow Pine mines, Potosi and Boss mines, it may be said that development has been confined entirely to the surface zone, and in no case has ground-water level been reached or the character of the primary ore definitely established.

Owing to its inaccessibility, and the complex nature of its ores, the district has been considerably handicapped by lack of capital to develop the various properties, and it is only in recent years that active and intelligent development has been in progress.

The Yellow Pine Mining Co. was able to solve its transportation problems by the construction of 12 miles of narrow-gage railroad, which has operated successfully during the past 5 years. The advent of motor trucks for ore haulage, with consequent improvement of roads, has greatly facilitated transportation from other properties and has resulted in increased tonnage, especially from those more remote.

The successful treatment of the mixed lead-zinc ore by various processes has now been fully demonstrated. The method employed by the Yellow Pine Mining Co. is a specialized application of ordinary gravity concentration methods, using rolls, jigs, and concentrating tables. Final concentration of the lead is effected by careful classification and table work, using specially designed equipment. The plant is essentially a separating plant, the process being to remove the lead minerals, the remainder of the ore, or what would ordinarily be known as tailing, being shipped as a zinc product. In 1916, the Yellow Pine Mining Co. milled 20,580 tons of ore averaging 10.5 per cent. lead, 30.4 per cent. zinc, and 4.6 oz. silver, from which was produced 2294 tons of lead concentrate, averaging 54.2 per cent. lead, 13.2 per cent. zinc, and 20.2 oz. silver per ton; 14,240 tons of zinc concentrate averaging 4.4 per cent. lead, 32.2 per cent. zinc, and 2.2 oz. silver; and 3525 tons of zinc slime, averaging 6.5 per cent. lead, 33.9 per cent. zinc, and 3.6 oz. silver per ton.

The scarcity of water in the vicinity has produced a type of dry concentrator which is giving good satisfaction, and there are now five plants of this type operating in the district, each having a capacity of about 50 tons per 24 hr. Dry concentrators of both the Stebbins and the Sutton, Steele & Steele type are used; the best results are produced in the separation of low-grade lead ores from calcite gangue, although the concentrators also effect a fair separation of the lead and zinc minerals.

At the Potosi mine, a calcining plant, similar to the ordinary lime kiln, is in use for treatment of the pure zinc carbonate ores. Oil is used

as fuel, and carbonate ore averaging about 34 per cent. zinc is raised to an average of over 40 per cent. zinc, with a shrinkage in weight of approximately 25 per cent., thus materially reducing freight charges and obtaining a premium for the higher-grade ores. This process has been found to be applicable only to pure carbonate ores, as the mixed silicate ores do not give good results.

A problem of the district which still remains unsolved is the treatment of the lower-grade zinc and mixed lead-zinc ores. Owing to the low gravity of the oxidized zinc minerals, no gravity process for separating them from the limestone gangue is applicable. Recent experiments in both leaching and oil flotation have given encouraging results and it is expected that the successful treatment of this class of ore will be a development of the near future.

The complex nature of the platinum-bearing ores of the Boss mine has presented many difficulties, but after extensive experimenting, a process has been evolved which bids fair to prove entirely successful in the extraction of the various metals. Owing to the inaccessibility of the mine and the high cost of labor and reagents, it was decided to erect the plant at Los Angeles rather than at the mine. In consequence, a separate corporation, known as the Palau Metals Co. was formed, and this company, headed by C. A. Overmire, of Los Angeles, the inventor of the process, entered into a contract with the Boss Gold Mining Co. for the exclusive treatment of its platinum-bearing ores.

A plant of 300-tons monthly capacity was erected in Los Angeles and has been in successful operation for the past 2 months. Details of the process are not divulged by the inventors, although a general outline may be given. The ore treated in the plant averages about 7 per cent. copper, 4 per cent. bismuth, 1.0 oz. platinum metals (platinum and palladium), 0.75 oz. gold, and 3.0 oz. silver per ton. This ore is crushed to 8-mesh at the mine before shipment to the Los Angeles plant. The crushed ore is dumped directly into bins from which it is fed to a 4 by 5-ft. Herman mill, which reduces it to 80-mesh, particles above this size being returned for regrinding. The pulp from the mill is elevated by a Frenier pump to 14 agitating tanks, where sulphuric acid is introduced to bring the solution to approximately 2 per cent. The agitating tanks are specially designed, agitation being produced by heavy oak propellors, belt-driven, and so hinged on ball bearings that friction is reduced to a minimum. The pulp is agitated for about 14 hr., the solution then decanted and the pulp washed with water. The acid solution, which contains practically all the copper content of the ore, together with about 20 per cent. of the platinum content, flows to tanks filled with scrap iron, which precipitates the copper as cement copper, containing also the platinum content of the solution. The cement copper from the precipitating tanks is collected periodically and forwarded to a refinery.

In order to remove the balance of the platinum contained in the pulp, together with the gold and silver content, it is treated with two successive leaches of calcium chloride, the sulphuric acid having been previously neutralized with lime. No details are available for the exact method used in precipitating the precious metals from the calcium chloride solution.

The treatment of this complex ore has involved many difficulties. Preliminary tests, involving a chloridizing roast before leaching, with which method it was hoped to precipitate all the valuable metals in one step, proved unsuccessful on account of the cementing action which took place after the acid solution was added to the roasted product, thus preventing a thorough solution of the metal content. The process now in use involves no roasting and all solutions are applied cold. The inventors of the process claim that operation to date indicates an extraction of approximately 92 per cent. of the copper content, and 96 per cent. of the platinum metals, gold, and silver. Over 90 per cent. of the bismuth content is also recovered and forms a valuable byproduct. On account of the experimental nature of the plant, no definite costs can be given, but it is expected that costs will not exceed $10 per ton, which figure may be reduced when the plant is enlarged to greater capacity.

With the advances being made in metallurgy, and as the knowledge of the ore deposits of the Yellow Pine district is extended, it becomes more and more evident that the district has before it an exceedingly prosperous future. It may be said that the exploration of the district is in only its earliest stage, and because of the exceptional size and richness of the varied deposits, it may be expected that future years will show considerably increased production from all sources of the district.

Phosphate in Egypt

BY E. CORTESE, C. E., E. M., ALEXANDRIA, EGYPT

(New York Meeting, February, 1918)

PHOSPHATE occurs in many places in Egypt, in two main zones: one in Upper Egypt, along the Nile Valley, principally on the right side, and one near the Red Sea coast.

In the Nile zone, the principal layers of phosphate rock are to be found: in the mountains east of Mahamid (right side of the valley); in the hills near Sibaiya, also called Sebaieh (both sides); in the hills of Agula, Hagaza and Gurn (right side); and further on, along the camel road leading from Kena to Kosseir, a few miles east of Legheita's Oasis.

Following that track, after having crossed the watershed, underlain by rocks like granite, serpentine, porphyry, and diabase, one comes again to the Cretaceous formation containing considerable quantities of phosphate, at Gebel Duwi, Gebel Nakheil, and Gebel Kosseir El Kadim, not far from the coast. More to the north, in the hills near Safaga Bay (Um El Uettat El Wasif) is another rich bed of the same formation. There are reports of phosphate existing near Suez and in the Sinai peninsula, and possibly some other zones can be traced or discovered in the future.

The mines are well developed on the right bank of the Nile at Sharawna (near Sebaieh Station) and along the Red Sea coast, at Safaga and near Kosseir. Prospecting work has been done at Gebel Duwi, Gebel Gurn, Agula, Hagaza, and near Mahamid.

The phosphatic formation in Egypt is quite variable, not only from place to place, but even within small areas.

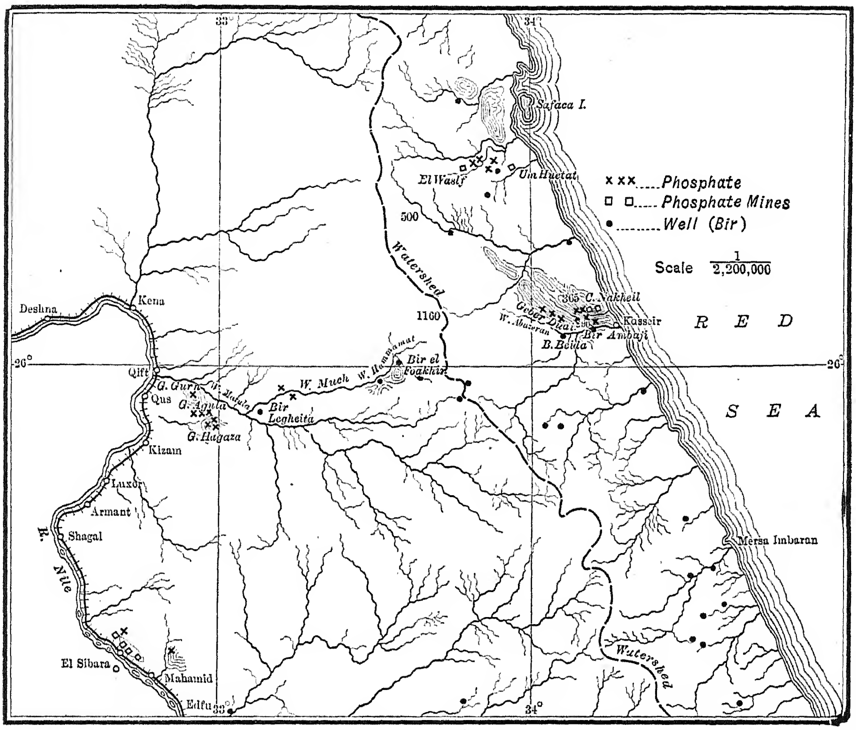
The phosphate is all of Cretaceous age, as is proved by the fossils found in it. It is considered to belong to the Campanian or, more appropriately, to the Maestrichtian series.

The principal fossils are: *Alectryonia Villei* Coq. sp.; *Roudereia Auressensis* Coq. sp. = R. Drui Mun. Chalm.; *Trigonoarca multidentata*, Newton.; *Cardita libyca*, Zittel; *Libycoceras Ismäely*, Zittel; *Nautilus* sp.; *Ancystrodon libycum Dam.; Corax pristodontus* Ag.; *Lamma biauriculata* Zittel sp.

Above the Maestrichtian beds, we have the Danian series, unconformably covered by Lower Eocene beds. Under the phosphate is a grayish marly clay, and beneath this, bluish-gray scaly shales resting on the Nubian sandstone (Santonian).

To describe all the variations in the phosphatic beds would be an endless task, and we shall try to point out only the principal features of the places that have been examined and studied. Nothing is said about Mahamid, because there is no work being done there.

Sharawna (*Sebaieh or Sibaiya*).—The village of Sebaieh is situated on the left bank of the Nile, but the railway station bearing its name is on the right and the phosphate mines are located in the hills, running along the railway line and supporting the two villages of Gibli and Bahkri (southern and northern) Sharawna.



THE PHOSPHATE MINING DISTRICT OF EGYPT.

The uppermost bed of the formation is a very hard limestone (1 m. to 0.60 thick) made up entirely of oyster shells, more or less crushed and strongly cemented by carbonate of lime. In places, this bed changes gradually into a true phosphatic bed; the oyster shells disappear little by little, the rock becomes softer, granulated, and in less than 300 m. (984 ft.) the hard bed is transformed into a fine tricalcic phosphate bed, running as high as 63 per cent. calcium phosphate.

Occasionally, the phosphate, instead of taking the place of the oyster bed, spreads underneath it and reaches a thickness of 70 cm. (2.3 ft.) and a percentage of 60 per cent. or, in other places, grows to a

thickness of 2 m. (6.5 ft.) and more, is very hard, full of small coprolites, but is not very rich (25 to 35 per cent. phosphate).

Underneath the oysters, or the above-described accidental phosphate bed, we have a band of whitish-yellow marly limestone (from 0.60 to 1.50 thick) and under this the main phosphate bed reaching sometimes the thickness of 2 m. or more, imbedded, generally, with boulders or strikes of hard, siliceous, poorer phosphate. The percentage in the main bed varies from 45 to 67 per cent., the richest, as a rule, being the upper part.

Occasionally, the bed is separated into two parts by a band of limestone, the upper part being very rich and the lower one, thicker than the former, of a low grade. The seam contains an enormous quantity of fish teeth (*Squalis*) and at its bottom, bones and teeth of saurians and chelonians. Generally this main seam rests upon a band of marly clay, stratified in yellow and light blue, which passes gradually into the underlying gray clay. In some places, though rarely, between the two clays there is a bed of phosphate, 0.50 m. (1.64 ft.) to 0.70 m. (2.29 ft.) thick, containing more than 70 per cent. of tricalcic and less than 2 per cent. of sesquioxide of iron and alumina, while the overlying seams run higher in such impurities.

The Sebaieh phosphate is already on the market, raw or ground. To be exported, it must be brought down the river to Alexandria, by barges. These barges are filled by automatically dumping buckets on a ropeway running to the Nile bank from centrally located stock piles. Special contrivances make it possible to utilize the ropeway at all times of the year, whether the river is in flood or not.

Lower-grade phosphate, running between 48 and 58 per cent., is transformed by a special treatment (Italian patent) into a kind of tetraphosphate, which can be used in place of superphosphate. All the phosphates, in this zone, are of a yellow, brownish, or light color.

Gebel Agula, Gebel Hagaza, Gebel Gurn.—In this range of hills, the phosphates are whitish, or of a light yellow tint, the upper beds being brownish-yellow.

The typical section shows a topmost phosphatic seam 2.5 m. (8.2 ft.) thick, an underlying band of lineated marls (4.2 to 4.4 m.) and beneath this a regular bed of phosphate (1.3 to 1.6 m.).

The three mountains contain no less than 50 million tons of phosphate but it is a poor quality, running from 14 to 48 per cent. of tricalcic phosphate, and from 32 up to 68 per cent. of silica, which makes it unmarketable.

Gebel Duwi.—Gebel Duwi is a single long, straight hill running 22 km. (13.67 miles) from N.N.E. to S.S.W. The strata of Upper Cretaceous outcrop all along the abrupt western side, outcropping horizontally and dipping gently toward the east, all with a striking regularity. The Nubian sandstone follows the foot of the long hill and dips in con-

formity with the overlying strata, under which it disappears. The tops are covered with Lower Eocene deposits.

Resting on the Nubian sandstone are the scaly shales, then the gray clay, and above this, the phosphatic beds. Only one of them is important

TABLE 1.—*Geological Section, Gebel Kosseir El Khadim, Etc.*

Description of Seams	Thickness, Meters	Percentage $Ca_3(PO_4)_2$
Hard marl, red or blue-brown	50–60	
Fossiliferous limestone	Variable	
Soft marl, reddish or violet	0.50	
White phosphate rock	0 15–0.25	Up to 75
Hard marl, yellowish	0.20–0.30	
White phosphate	0.50–0.70	Up to 73–74
Hard limestone, white (crushed fossils)	0.15–0.20	
White phosphate	0.40–0.70	Up to 71–72
Hard limestone as above, white	0.50–0.40	
White phosphate	0.10–0.15	Up to 69–70
Marls and limestone	0.30–0.60	
Hard whitish phosphate	0.10–0.20	Up to 50–60
Limestone and hard marls with plenty of flinty or cherty beds and occasionally small seams of hard, grayish-white, poor phosphate.	18–20	
Grayish-white phosphate (with a parting of flint at the upper part like at Gebel Duwi)	0 80–1.50	Up to 63–70
Marl and limestone with brown chert fading to white, and two big zones of fossiliferous limestones	20–24	
Occasionally seams of hard brown siliceous phosphate.		
Brown yellowish phosphate	1.80–1.90	Poor
Laminated marl	3.20	
Alternating beds of marl and yellow phosphate, one of which is 1.30 m. thick	4.00	Phosphate beds running 48, the thickest 53
Marls	2.30	
Phosphate bed	0.60	38
Gray or greenish marls		

for its thickness, regularity and percentage in tricalcic phosphate. It is a grayish white bed, with a parting of blackish flint, showing 0.30 m. (0.98 ft.) of good material above it and 1 m. (3.28 ft.) underneath.

Although the strata are dipping unfavorably and the roof is not very solid, this phosphate field is a very important one and its exploitation will prove profitable. The shortest distance from Kosseir harbor, on the Red Sea, is about 27 km. (16.77 miles), which can be easily traversed by a narrow-gage railway.

Gebel Kosseir El Khadim, Gebel Nakheil, Gebel Anz.—This is a group of hills, cut by various wadis (valleys), where the phosphate occurs in large quantity. The phosphatic series rests, as usual, on the gray (sometimes greenish) clay, and is covered with limestones or marls, but

is a good deal more complicated than anywhere else. Table 1 shows a typical section of the bed.

In other parts of this zone, the series varies in thickness and number of phosphatic seams, but the general outlines of the formation remain the same. In this part of the eastern Egyptian desert it is estimated that there is no less than 50 million tons of phosphate, but only a small proportion of it is marketable.

The white phosphate is very good and high grade, as it runs generally higher than 70 per cent. and contains less than 1 per cent. of sesquioxide of iron and alumina. More than 3 million tons has been estimated as existing here, and a great part is already stoped. The richness of the formation and good quantity of phosphate are really striking.

Although a regular export of this material has not been established, on account of the war, some thousands of tons have been shipped to England and the phosphate has been found satisfactory.

Narrow-gage railways (0.75 m.–2.45 ft.) 12 km. (7.5 miles) long connect the mines with the harbor where a landing pier and a big ropeway are set for the shipping of the phosphate. A grinding plant is to be put up later.

Safaga.—At Um Wettat and Um Wasif are two big mines largely worked out since 1911. Good plants exist at Safaga Bay for the shipping of phosphate (pier and ropeway). Thirty kilometers of 1-m. gage railway lead from Um Wettat to the sea, and a branch, 12 km. long, joins El Wasif with the same. The mines are very rich and profitable, the quantity of phosphate very large. The typical section above the Nubian Sandstone is given in Table 2:[1]

TABLE 2.—*Geological Section; Safaga At Um Wattat.*

Description of Seams	Thickness, Meters	Percentage $Ca_3(PO_4)_2$
Upper limestones, grayish phosphate bed	1.80	60
Cherty and flinty beds with thin bands of siliceous phosphate	5.00	
Yellowish phosphate bed	1.30	50–75
Gray and brown laminated clay	9.00	
Brown-yellow phosphate	2.00	20–45
Brown-gray laminated clays	25.00	
Nubian sandstone	....	....

From this brief outline, one can see that Egypt, while not yet a very large phosphate-producing country, contains large deposits of phosphates, and if the utilization of the poorer qualities, as fertilizers, can be extended, a large quantity of them can be obtained without great expense.

[1] John Ball: *Egyptian Survey Department Paper* No. 29.

The Wisconsin Zinc District

BY H. C. GEORGE,* B. S., E. M., PLATTEVILLE, WIS.

(New York Meeting, February, 1918)

Introduction

The Wisconsin Zinc District, or the Upper Mississippi Lead and Zinc District as it is often called, lies in the southwestern corner of Wisconsin, in Grant, Iowa and Lafayette Counties, and it includes adjoining parts of Illinois and Iowa.

The district is about 70 miles long, north and south, and about 40 miles wide, east and west. It lies wholly within what is geologically known as the non-glaciated area of the Upper Mississippi Valley.

History of the District

The district was first opened up as a lead producer in 1822. From this time until 1860, about 205,000 tons of cog lead (galena) and washed lead (galena) was produced from shallow crevices and openings. From 1860 to 1900, about 74,500 tons was produced, and since that time, from 5000 to 7000 tons has been produced annually. Since 1900, most of the lead concentrate produced has been as a byproduct of the zinc mines.

The first zinc ores were mined about 1862. These were the carbonate ores, locally known as "drybone." Very little zinc blende was mined in the district, previous to 1875. The zinc blende ores mined from 1875 to 1900 were mostly of the high-grade, hand-cobbed, sheet-ore class, which usually contained from 45 to 60 per cent. metallic zinc. Such mines as the "Sallie Waters," "Quinlin," "Lead Mine," "Benton Blende," and "Ida Blende," located near Benton, Wis., were mines which produced ores of this type, during this period. The mines located at Highland, the "Coker Mine" located at Livingston, Wis., and the "Opencut Mine" located at Shullsburg, Wis., were mines that were heavy zinc carbonate producers, previous to 1900.

The production of zinc ores in the district from 1862 to 1890 was about 283,500 tons, mostly zinc carbonate, with a probable average metallic zinc content of 30 per cent. From 1890 to 1903, the production

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* Consulting Mining Engineer.

of the district consisted of about 126,000 tons of hand-cobbed and hand-jigged zinc carbonate and zinc blende.

During the last few years of the 19th century, there was a decline in the production of both lead and zinc ores in the district. Since 1903, the revival of the district as a producer of zinc blende, and incidentally zinc carbonate and lead, has taken place as a result of the advance in the price of lead and zinc ores.

Since 1903, the modern methods of mining and milling lead and zinc ores with power machinery, used in the district, have placed the mining industry on a stable basis. Nearly all of the district production consists of concentrates containing mixed zinc and iron sulphides, with an average zinc content of about 35 per cent. The magnetic separation of low-grade roasted zinc blende concentrates has greatly broadened the field of operations. Zinc concentrates, ranging in metallic zinc content from 20 to 40 per cent., are roasted, the iron sulphides magnetized and removed magnetically and a finished zinc blende product is produced which will assay from 58 to 61 per cent. metallic zinc.

Table 1.—*Lead Production from Mines*

Year	Tons of Lead Concentrates
1822–1860	205,000
1861–1900	74,500
1901–1916	84,000

Table 2.—*Zinc Production from Mines*

Year		Tons of Zinc Concentrates
1862–1890	Carbonate and blende	283,500
1891–1903	Blende and carbonate	126,000
1904	Mostly blende	19,300
1905	Mostly blende	33,000
1906	Mostly blende	39,363
1907	Mostly blende	53,011
1908	Mostly blende	58,135
1909	Mostly blende	75,528
1910	Mostly blende	102,070
1911	Mostly blende	107,253
1912	Mostly blende	119,280
1913	Mostly blende	105,877
1914	Mostly blende	134,398
1915	Mostly blende	163,916
1916	Mostly blende	219,128

General Geology

The strata of the district consist of a series of Silurian and Ordovician limestones, shales, and sandstones, underlain by Cambrian sandstones and pre-Cambrian crystalline rocks.

		Feet
Silurian	Niagara limestone	50
Ordovician	Mequoketa shale	160
	Galena limestone	230
	Platteville limestone	55
	St. Peters sandstone	70
	Lower Magnesian limestone	200

Erosion has exposed all of these formations in some part of the district. Nearly all of the Niagara and Mequoketa formations have been eroded away. The Platteville, Belmont, and Sinsinawa Mounds in Wisconsin and the numerous mounds in northwestern Illinois are all that remain of this formation in the district.

There is an east and west unbroken ridge in the northern part of the district, known as Military Ridge. A north and south ridge extends from this ridge, south through the middle of the district for a distance of about 30 miles (48 km.). It is along these two ridges that the local branch of the Chicago & Northwestern Railroad is built. The formations exposed on these two ridges are the upper part of the Galena limestone and the lower part of the Mequoketa shale. The ground slopes north and south from the east and west ridge, and east and west from the north and south ridge, to drainage basins. The streams located in these drainage basins have cut down through the formations, so that at various points along their courses, the Platteville limestone, the St. Peters sandstone and the Lower Magnesian limestone formations are exposed.

The rock formations of the district dip to the south-southwest, descending about 20 ft. per mile (1.9 m. per kilometer). The strata have also been compressed and folded slightly, producing a series of synclines and anticlines and structural basins. The main axis of most of the basins is east and west, produced by lateral pressure from the north and south. The secondary axis of the basins is north and south, produced by an east and west lateral pressure. Frequently one leg of these synclines or one side of these basins will dip more steeply or show changes in slope. At these points the orebodies usually occur, located in either the lower part of the Galena formation or the upper part of the Platteville formation or in both.

The Galena formation consists of heavily bedded dolomites, interbedded with chert beds and nodules and thin bedded clay shales. The base of the formation consists of thin bedded, brown carbonaceous shales, from 1 to 15 ft. (0.3 to 4.5 m.) in thickness. These shales are known as the "oil rock." The bottom of this shale marks the base of the Galena limestone formation. A blue clay shale usually occurs, immediately below the oil rock. This shale varies from a few inches to 6 or 7 ft. in thickness and is known as the "clay bed." Immediately below the clay bed is the "glass rock," a fine compact limestone, usually gray or brown in

color, which breaks with a conchoidal fracture, from which characteristic it derives its name. At some places there are shale beds resembling the oil rock, between the clay bed and the glass rock. At other places there is practically no oil rock, and at still other places there is no clay bed. The base of the glass rock marks the base of the ore-bearing formations,

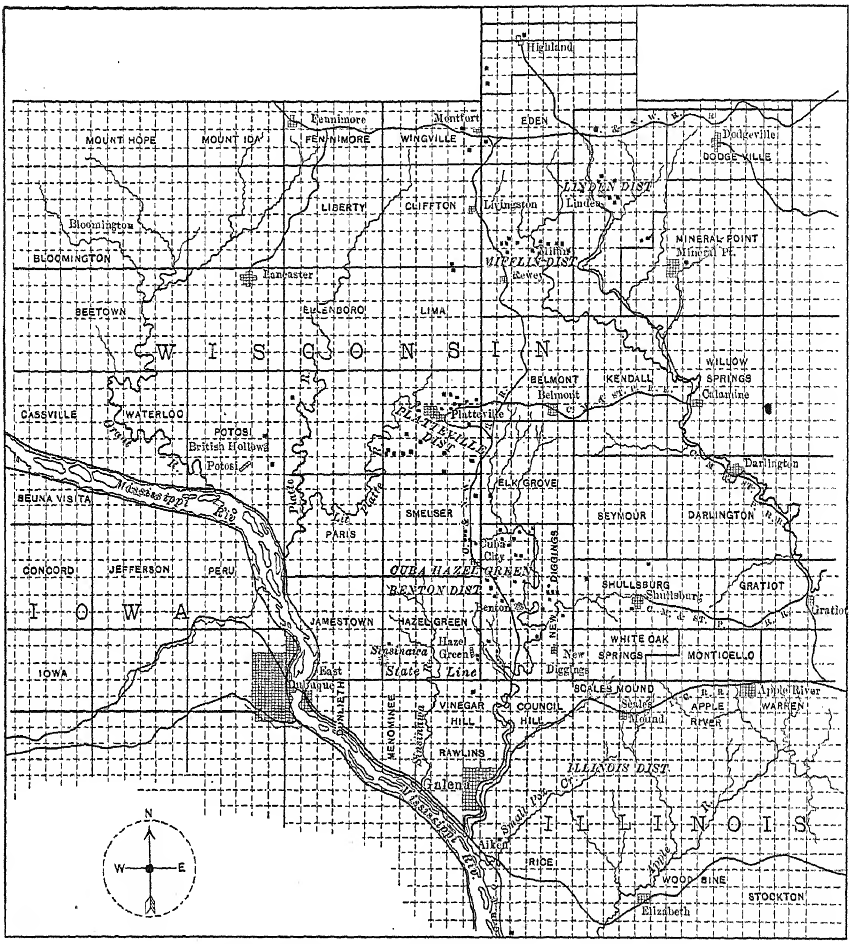


FIG. 1.—MAP OF THE WISCONSIN ZINC DISTRICT

as worked up to the present time, but recent discoveries made at the Winskell mine, east of New Diggings, Wis., indicate that ore in paying quantities occurs in the Platteville limestone formation, nearly down to the top of the St. Peter sandstone formation. The lower part of the Platteville limestone formation consists of thick-bedded dolomites, similar to the dolomites of the Galena limestone formation.

The Origin of the Ores

The general supposition is that the ore has been dissolved out of the Galena limestone and the overlying Mequoketa shale, in which it is found, and deposited in the crevices and openings existing in the lower part of the Galena limestone formation and the upper part of the Platteville limestone formation in the structural basins.

The crevices and openings in which the ore occurs may have been produced in several ways. The lateral pressure and the resulting folding may have produced them, or the dolomite beds for several feet immediately above the impervious oil rock may have been dissolved out along channels in the structural basins, producing slumps in the overlying strata; or, as suggested by H. Foster Bain, the oil-rock layer, containing much organic matter, and being much thicker in certain parts of the structural basins, in the changes which the bed has undergone, has decreased in thickness to a considerable degree, in the same manner that coal beds have decreased in thickness, producing a slump in the overlying formations at points where the oil rock is the thickest.

The Ore Deposits

Erosion, ground-water level and the physical and chemical differences of the different formations in which the orebodies occur have produced different types of ore deposits.

Fig. 16 shows a vertical cross-section from the Mequoketa shale to the base of the glass-rock formation. All of the known orebodies of the district occur at some horizon in this vertical section. If the orebody occurs at points marked *A*, *B*, or *C* in Fig. 16, it will be of the types shown in Figs. 4 and 10. If the orebody is above ground-water level, the ore will consist of galena as "cog lead," zinc carbonate, or zinc blende or all of these minerals occurring together. This type of orebody is known locally as a "crevice" or an "opening" deposit.

Practically all of the lead mined in the district previous to 1900 was secured from this type of orebody. Recently mines of this type have been worked below ground-water level. Such mines are the "Board of Trade," the "Wicklow," and the "M & D" at Cuba City, Wis., and the "White Rose" and "Merry Widow" west of Galena, Ill. Orebodies of this type are frequently rich but limited in production. This type of orebody is supposed to have been formed in the following manner; certain rock strata at a given horizon are dissolved for a short distance on either side of a vertical or nearly vertical crevice, and the opening is simultaneously or later filled with lead and zinc ores, chemically deposited.

If the orebody occurs at points marked *D*, *E* and *F*, Fig. 16, and is

not the upper part of an orebody, which extends to a lower level, it is frequently of the type shown in Fig. 9, a vertical cross-section of the

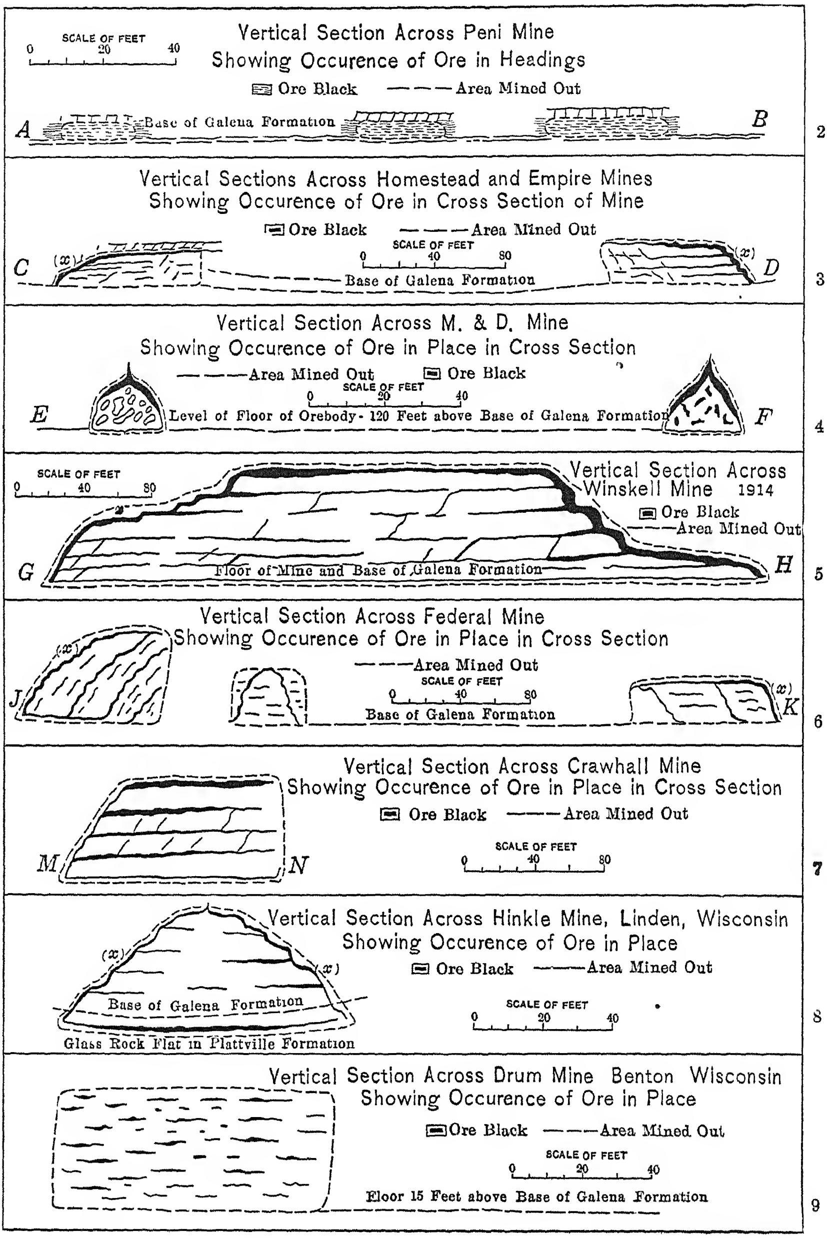


Fig. 2 to 9.

Drum mine, located east of Benton, Wis. In this type of orebody there are no distinct sheets of zinc blende. The ore is disseminated or

"sprangled," or, in other words, the ore exists as small gash veins. Orebodies of this type have never been of much importance or very long-lived. They are locally known as "bunches," occurring where a series of crevices cross at right angles.

The important mines of the district are those that occur in the lower part of the Galena limestone formation, above the oil-rock formation, between *E* and *G*, Fig. 16. These are the true "flat and pitch" formations, usually located below ground-water level. The flats are sheets of ore along the horizontal bedding planes of the strata and the pitches are sheets of ore located in vertical or dipping crevices.

Flats are shown at *M*, Fig. 16, and pitches are shown at *N*, Fig. 16. Vertical cross-sections of orebodies of this type are shown in Fig. 3, 5, 6, 7 and 8 and plan views are shown in Fig. 11, 12, 13 and 15.

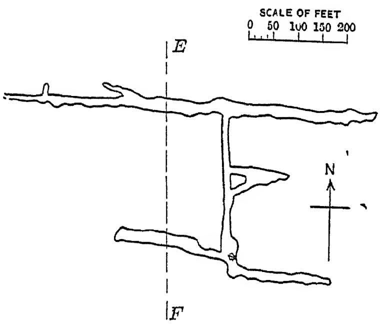


FIG. 10.—M. & D. MINE, CUBA CITY, WIS.

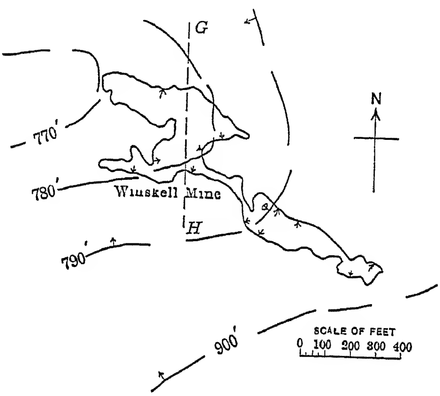


FIG. 11.—WINSKELL MINE, NEW DIGGINGS, WIS.

Fig. 3 shows a vertical section across the Homestead and Empire mines at Platteville, Wis. This cross-section is taken on the vertical section line *C–D*, shown in Fig. 15, the plan map of the same mines. These orebodies lie in a broad flat structural basin. The Grant County and the Homestead mines are located along the north side of the basin, and the Enterprise, Empire and Royal mines are located along the south side of the basin. The distance from one group of orebodies to the other group, across the basin, is about 1000 ft. (304 m.). The Acme mine is at the east end of the basin, and shows indications of being connected with both series of orebodies, as it has both north and south pitches, and has been connected with the orebodies along the north side of the basin by prospect drilling. As shown in Fig. 3, this is the type of orebody in which most of the ore and the thickest sheets of ore are found in the main, or outside, pitch, and the top flat is the only flat that shows

any great thickness of ore. Variations occur in this type of orebody, from those in which all or nearly all of the ore occurs in the outside pitch, to those that show ore in paying quantities in the top flat and the underlying core down to the base of the formation.

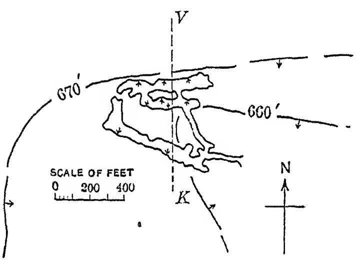


FIG. 12.—FEDERAL MINE, HAZEL GREEN, WIS.

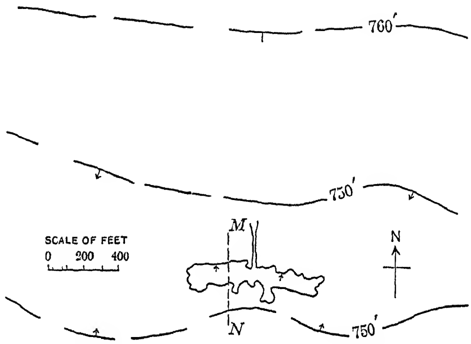


FIG. 13.—CRAWHALL MINE, NEW DIGGINGS, WIS.

Such mines as the Empire and the Enterprise at Platteville, Wis., illustrate the type, where the main or outside pitch and the top flat are

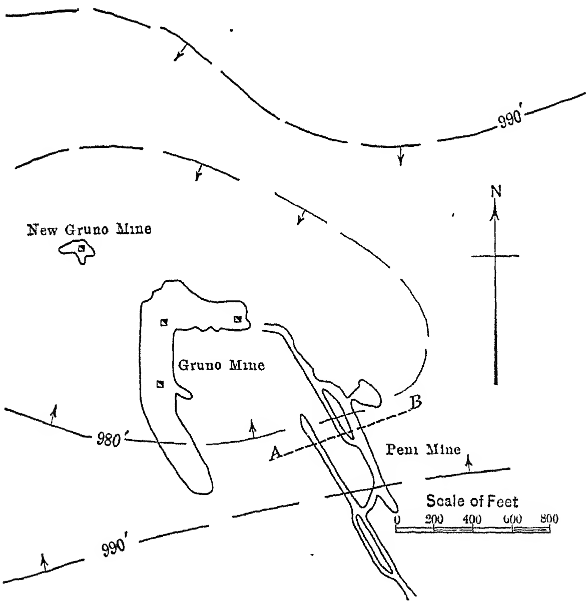


FIG. 14.—MIFFLIN MINES.

strongly developed, and such mines as the Klar-Piquette and the East End at Platteville, Wis., illustrate the type of orebody, where the top flat and several underlying flats are strongly developed and the outside

or main pitch contains very little ore, at many places showing nothing more than a crack or crevice.

Fig. 5 shows a vertical section across the Winskell mine, located east of New Diggings, Wis. This section is taken on the vertical section line *G–H*, Fig. 11, the plan map of the same mine. This is the type of orebody located in a narrow, steep, structural basin, and mineralized in the main part of the orebody, from one pitch to the other, or from one side of the structural basin to the other side. In this type of "flat and pitch" formation, the flats and pitches seem to be about equally developed, as regards the thickness of ore that they carry. The Frontier mine

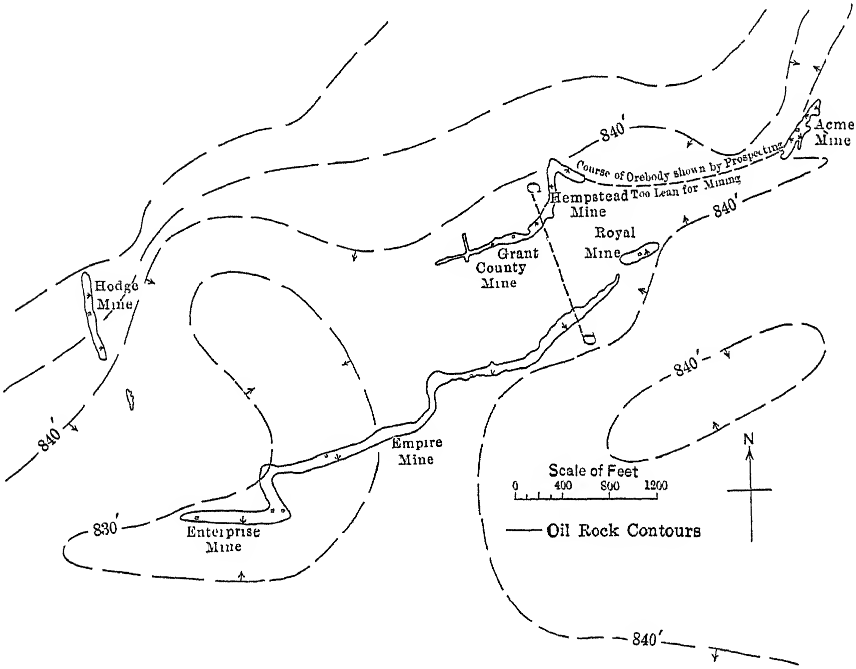


FIG. 15.—PLATTEVILLE MINES.

at Benton, Wis., and the Vinegar Hill mine north of Galena, Ill., are also mines of this type.

Fig. 6 shows a vertical section across the Federal mine at Hazel Green, Wis. This section is taken on the vertical section line *J–K*, Fig. 12, the plan map of the same mine. This type of orebody is located in a structural basin similar to the one in which the Winskell mine is located. Nearly all of the ore is located in a series of pitches, and flats along the bedding planes show only to a minor extent.

Fig. 7 shows a vertical section across the Crawhall mine at New Diggings, Wis. This section is taken on the vertical section line *M–N*, Fig. 13. This type of orebody is located in the bottom of a broad, flat

structural basin. In this type of orebody, nearly all of the ore occurs in the flats along the bedding planes.

Fig. 8 shows a vertical section across the Hinkle mine at Linden, Wis. This is the type of orebody with both pitches about equally developed, and flats extending from these pitches back into the core of the mine. There is also a flat sheet of zinc blende extending from the foot of one pitch to the foot of the other, in the glass-rock formation.

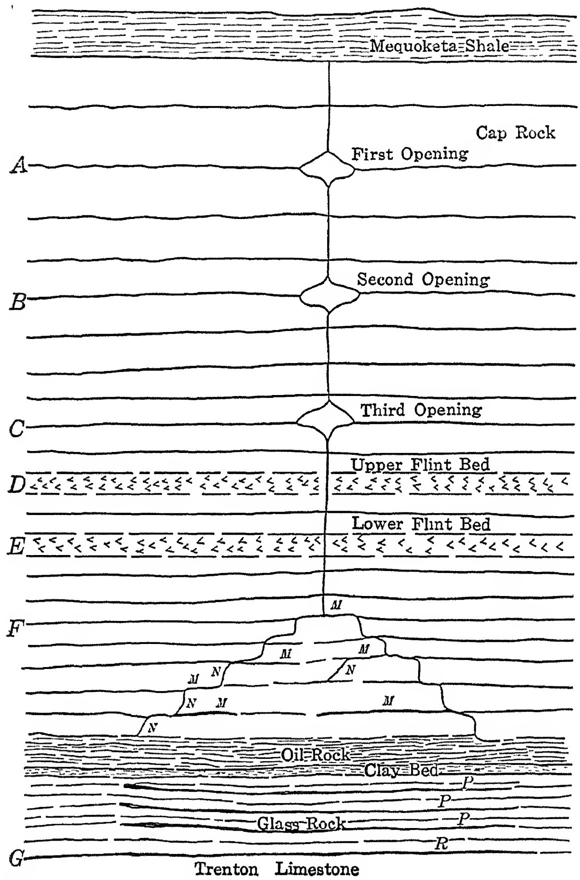


FIG. 16.—VERTICAL CROSS-SECTION OF ORE-BEARING FORMATIONS.

This type of orebody is located in narrow depressions or channels in the structural basins. Nearly all of the orebodies near Linden are of this type, and this is the type of orebody which has been used as an illustration of the orebodies of the district, in the publications of 10 years ago, regarding the district.

Fig. 2 shows a vertical section across the Peni mine, located at Mifflin, Wis. This section is taken on the vertical section line *A–B*, Fig. 14. This type of orebody is usually located in the oil rock or the glass rock,

and it frequently follows a series of parallel or intersecting crevices, extending from the surface to the point of the location of the orebody. The ore is usually disseminated, sprangled, or in the form of irregular flat sheets. The Kennedy and the Wallace mines at Highland, Wis., are examples of this formation. Orebodies of this type frequently produce the highest-grade zinc blende concentrates of the district, often running from 55 to 60 per cent. metallic zinc from the mill jigs.

There are numerous variations and modifications of all of the types of orebodies shown in the previous classification, and new features are being found constantly in the orebodies of the district.

The chief production of the district comes from the mines located in its southern half, most of these mines being of the types shown in vertical sections Figs. 3, 5, 6, and 7.

Prospecting

Prospecting in the district may naturally be divided into drifting, shaft sinking, and churn drilling.

Previous to the year 1908, nearly all of the lead and zinc mines were found by shaft sinking and drifting on crevices and outcrops. As most of the operations were conducted without power machinery, the ground-water level marked the limits to which these operations extended. During the latter part of this period, the only machinery used in connection with prospecting and mining operations below ground-water level consisted of the horse whim for hoisting and the horse-operated pump, and these were used successfully only in connection with the larger ore deposits.

The diamond drill has been tried in the district at several places, but without success. The numerous crevices and openings have interfered with its operation.

During the past 10 or 15 years, most of the larger orebodies have been found by churn drilling, which has given the best results of any method of prospecting so far used in the district.

When the ore-bearing formations are reached, the hole is sludged out every 2 or 3 ft., and the sludgings that show zinc blende to the naked eye are assayed for zinc and iron. Complete records of these holes are kept, showing the location of the drill hole, the surface elevation at its location, the nature, thickness, and position of the formation passed through and the position and amount of the ore discovered.

Estimates based on several prospect drill holes are not always reliable, for more ore than actually exists may be shown by ore dropping from an upper to a lower level, especially when the formations are loose, thus salting the hole, as shown in Fig. 17, or less ore may be shown than is actually drilled through, because it may be washed into crevices or openings in the rock through which the drill hole passes, as shown

in Fig. 18. A drill hole should never be "shot" to show the nature of the ore passed through, until the hole is completed, because "shooting" may loosen ore and cause it to salt sludgings at lower levels.

One of two methods is usually employed for getting the average zinc and iron content of a prospect drill hole. The first is to assay each sludging, and then take a footage average of all of the sludgings from the first one containing ore to the last one containing ore and including intervening sludgings not containing ore; and the other method is to take all of the sludgings included in the former method, mix them thoroughly together, and take one assay of the entire sample. An example (Table 3) of a prospect drill hole in actual practice, assayed by both methods, illustrates the method and shows how slight errors may occur in both.

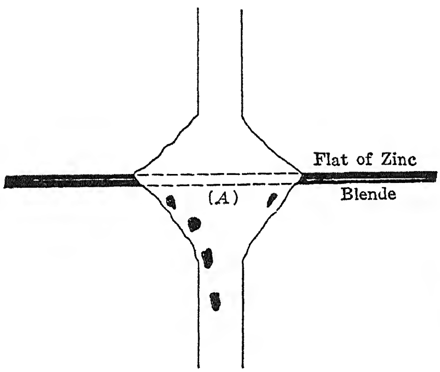


FIG. 17.—VERTICAL SECTION OF DRILL HOLE SHOWING ORE DROPPING FROM FLAT IN SOFT GROUND AND SALTING THE HOLE BELOW.

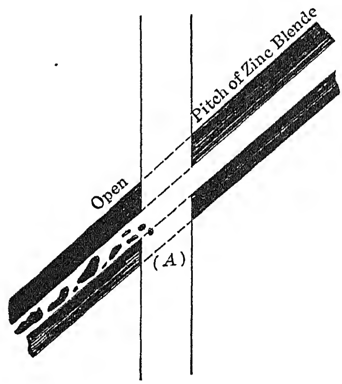


FIG. 18.—VERTICAL SECTION OF DRILL HOLE SHOWING ZINC BLENDE CUTTINGS BEING LOST IN AN OPEN PITCH.

TABLE 3.—*Drill Hole Records and Assays*

	Depth	Zinc Assay	Iron Assay
First Method	116–120	14.8	3.0
	120–122	20.6	5.8
	122–124	10.0	2.8
	124–126	12.6	3.8
	126–128	11.4	3.0
	128–132	2.8	1.4
	132–134	9.6	9.4
	134–142	2.8	6.4
Total........	26 ft.—ave.	8.5 per cent. zinc	4.5 per cent. iron
Second Method			
Total........	26 ft.—ave.	7.8 per cent. zinc	4.8 per cent. iron

The difference in the assays in the two methods is due to the fact that equivalent footages of sludgings do not always produce the same

volumes of sludgings, because of the physical conditions existing in the strata drilled through, as previously explained. Each method has its advantages. Both should be used as a check for careful work.

Most of the churn-drill prospecting of the past 10 years, and the resulting discovery of zinc blende mines, has been at or near the old, shallow lead and zinc carbonate workings. The old shafts and mine waste dumps have received far more consideration up to the present time, in determining where prospecting should be done, than outcrops, crevices and geological strata and structural conditions. But these shallow, old workings, not further developed by churn-drill prospecting,

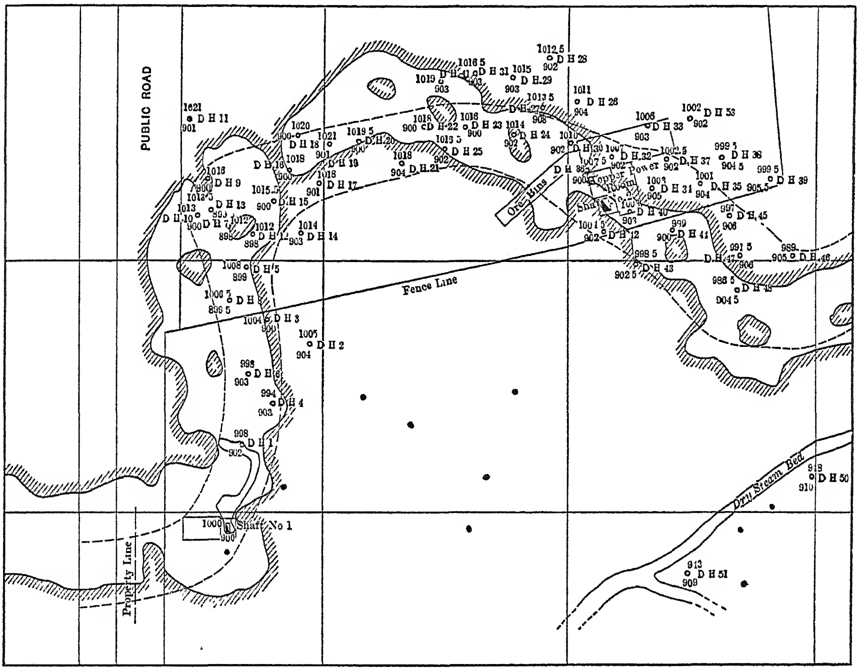


Fig. 19.

are becoming scarce, so that the future developments will have to be made more and more in connection with knowledge of geological and structural conditions.

After good ore is found in a prospect drill hole, located on an orebody, there is no great difficulty in proving up the extent of the orebody, unless it is very narrow or crooked in its course.

Fig. 19 shows one of the orebodies of the district blocked out by prospect drill holes. The broken lines represent the walls of the mine as blocked out for estimates of tonnage, from drill hole records before any mining was done; and the full line shows the walls of the mine after the mine was worked out.

The orebodies of the district vary from 20 to 300 ft. (6 to 91 m.) in width, from 5 to 70 ft. (1.5 to 21 m.) in height and from 500 to 7000 ft. (152 to 2128 m.) in length.

One of the best orebodies of the district had a length of 7000 ft. (2128 m.), an average height of 20 ft. (6 m.) and an average width of 80 ft. (24 m.). Another has a length of 800 ft. (243 m.), a width of 500 ft. (152 m.). and a mean height of 40 ft. (12 m.).

Estimates of Values. A Hypothetical Orebody Tonnage and Values from Prospect Drill Hole Assays

Fig. 20 is a plan map of a hypothetical orebody blocked out for a total length of 1000 ft. (304 m.) by prospect drill holes. The west 600 ft. (182 m.) of this orebody shows an average width of 80 ft. (24 m.). The east 400 ft. (121 m.) of the orebody shows an average width of 120 ft. (36 m.), with a higher zinc content and a lower iron content for the

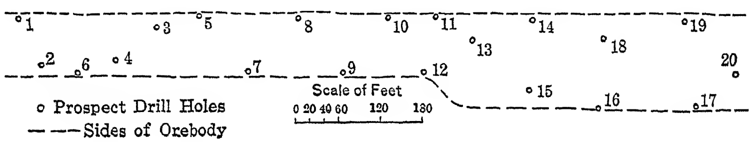


Fig. 20.—Hypothetical orebody.

average assay of the prospect drill holes than the west 600 ft. The west 600 ft. of mine had 12 prospect drill holes in ore and the east 400 ft. had eight prospect drill holes in ore. On the basis of the assays of these drill holes the thickness, width and length of the orebody, I will make an estimate of tonnages, grades and values, using the same costs as the State Tax Commission has used as the average of the district.

West 600 *Ft. of Orebody*

Hole No.	Footage	Zinc Assay	Iron Assay
1	40	7.8	6.2
2	29	4.2	8.8
3	39	3.0	5.5
4	22	7.3	10.4
5	36	7.0	4.1
6	6	2.1	6.7
7	26	10.7	7.0
8	43	12.6	5.4
9	22	8.6	6.0
10	33	2.8	2.9
11	31	5.2	7.0
12	18	4.1	12.0
Average	28.7	6.73	6.42

East 400 *Ft. of Orebody*

Hole No.	Footage	Zinc Assay	Iron Assay
13	33	11.1	5 4
14	63	6.5	6.4
15	29	8.0	2.0
16	4	13.8	7.6
17	7	8.3	12.6
18	69	8.2	7.7
19	83	4.0	5.8
20	45	9.7	2.6
Average	41.6	7.37	5.66

Concentrating (milling) operations in the district have shown that about 70 per cent. of the metallic zinc contents, and about 50 per cent. of the metallic iron contents of the ore as shown from the prospect drill hole records is recovered in the concentrates. I will use these factors to show recovery from drill-hole assays.

West 600 *Ft. of Orebody*

6.73 by 0.7 = 4.711 recoverable zinc; 4.711 by 1.5 = 7.07 per cent. received ZnS.
6.42 by 0.5 = 3.21 recoverable iron; 3.21 by 2.2 = 7.06 per cent. received FeS_2.
7.07 plus 7.06 = 14.13 per cent. recoverable mineral as concentrates.

$$\frac{4.711}{14.13} = 33.3 \text{ per cent. zinc in concentrates.}$$

28.7 by 80 by 600 = 1,377,600 cu. ft. (12 cu. ft. = 1 ton)
= 114,800 tons ore in place.
(Based on 5-c. spelter, $40 per ton for 60-per cent. zinc concentrates, 33.3-per cent. zinc concentrates will be worth $17 per ton.)
114,800 by 0.1413 = 16,221.2 tons of 33.3-per cent. zinc concentrates.
16,221.2 by $17 = $275,760.40, gross value of concentrates.

East 400 *Ft. of Orebody*

7.37 by 0.7 = 5.159 recoverable zinc 5.159 by 1.5 = 7.74 per cent. received ZnS.
5.66 by 0.5 = 2.83 recoverable iron 2.83 by 2.2 = 6.23 per cent. received FeS_2.
7.74 plus 6.23 = 13.97 per cent. recoverable mineral as concentrates.

$$\frac{5.159}{13.97} = 36.8 \text{ per cent. zinc in concentrates.}$$

41.6 by 120 by 400 = 1,996,800 cu. ft. (12 cu. ft. = 1 ton)
= 166,400 tons of ore in place.
(On same basis as above 36.8-per cent. zinc concentrates will be worth $20 per ton).
166,400 by 0.1397 = 23,246.1 tons of 36.9-per cent. zinc concentrates.
23,246.1 by $20 = $464,922 gross value of concentrates from east 400 ft. of mine.
$275,760.40 gross value of concentrates from west 600 ft. of mine.
$740,682.40 total value of zinc concentrates.

Tons ore in place—west 600 ft.	114,800
Tons ore in place—east 400 ft.	166,400
Total	281,200
50 per cent. added for ground broken outside of drill holes (see Fig. 21)	140,600
Total tonnage to be mined	421,800

The average operating cost as shown by the report of the Wisconsin Tax Commission is about $1.25 per ton mined, I will use this figure for the estimates.

Operating cost—421,800 tons at $1.25	$527,250.00
Cost 150-ton mill and mining equipment	30,000.00
Total	$557,250.00
Gross value of concentrates	$740,682.40
Less 10 per cent. royalty to landowner	666,614.16
Operating cost, mill and equipment	557,250.00
Operating profit	$109,364.16

A concentrating plant such as planned for the above property, running two shifts per day and "culling" the "boulders" before the mine ore, or "dirt," goes to the crusher, will handle about 100,000 tons of mine ore per year, so that the life of the mine would be about 4.2 years.

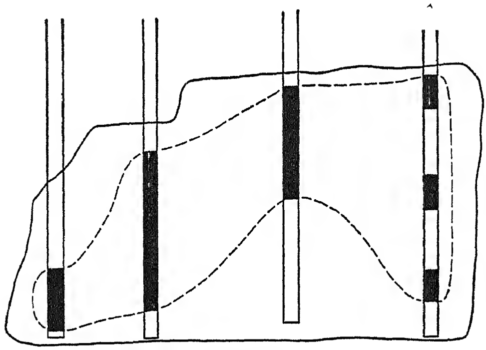


FIG. 21.—VERTICAL CROSS-SECTION OF OREBODY SHOWING FOUR PROSPECT DRILL HOLES.

Some of the mining companies of the district own the property on which they mine, but most of the mining operations of the district are conducted on leased land. The land owner generally receives 10 per cent. of the gross receipts of sales of ores. Technically this 10 per cent. is part of the profit, but from the standpoint of the mining company it is an operating expense.

MINING METHODS

Shafts

The mines vary in depth from 75 to 200 ft., and the shafts sunk are usually vertical and vary in size, depending upon the tonnage to be handled, the depth of orebody, and the amount of water to be raised. Common sizes for shafts are 5 by 7 ft (1.53 by 2.14 m.); 5 by 9 ft. (1.53

by 2.75 m.); 6 by 10 ft. (1.83 by 3.05 m.); 7 by 12 ft. (2.14 by 3.66 m.) and 7 by 14 ft. (2.14 by 4.27 m.).

Shafts seldom have to be cribbed to a greater depth than 30 ft. (9 m.), but there are cases where cribbing has been necessary to a depth of 75 ft. (23 m.). The different kinds of cribbing used are 4 by 10-in. (10.2 by 25.4-cm.) plank, or 6 by 6-in. (15.2 by 15.2-cm.) timber in soft ground, or in small mines 2 by 10-in. (5.1 by 25.4-cm.) plank.

Several shafts in the district have been cribbed with reinforced concrete. A recent State law limits the size of the shaft hoisting compartment to 5½ by 5½ ft. (1.68 by 1.68 m.) in the clear, when power machinery is used for hoisting.

Most of the shafts are sunk from 5 to 10 ft. (1.5 to 3 m.) deeper than the deepest mine level. This last 5 or 10 ft. is floored over and is used as a sump from which all of the mine water is pumped.

Nearly all mine shafts are equipped with ladders, usually of the vertical continuous type, without landings. These ladders are usually made with uprights of 2 by 4-in. (5.1 by 10.2-cm.) pine, and the rungs are usually hard wood or pipe. In most cases these ladders are used only for emergency, the men being hoisted from and lowered to the workings in the cage or tubs used for hoisting ore.

The cost of shaft sinking in the district varies from $7 to $50 per foot, depending upon the size, depth and amount of water to be pumped.

Pumping

The amount of water to be pumped from the mine workings varies from a few gallons to 3000 gal. per minute. Several of the largest mines of the district have pumped so little water that a supply for jigging the ore in the concentrating process has had to be secured from other sources. Others have had so much water that they run their mine water direct to the concentrating plant and require no pond for return water.

The pumps used are the different types of one-stage lift pumps, such as the "Cornish Walking Beam," the "Cross Head," and the "Steam Head" and different types of one- and two-stage motor-driven centrifugal pumps, and motor-driven triplex pumps.

The water pumped is usually not acid, so that there is seldom difficulty due to its chemical action on the pumping equipment. Most pump troubles are caused by the blowing out of gaskets, or the wearing out of packing, or the breaking of pump rods and parts.

General Underground Work

The method of working a mine in the district depends upon the size, shape and position of the orebody. When this has been blocked out by

prospect drilling, the shaft is located at the most desirable point, usually near the middle of the orebody or at the lowest point in the structural basin, or at the point where the orebody is the deepest.

Most of the orebodies lie in a horizontal or nearly horizontal position, so that they can be worked from one level, or at least the ore can be hoisted from one level, all of the ore being broken down to this level, or dumped into hoppers, from which it is drawn at this level. If the orebody is of the long, narrow type, several shafts may be sunk, and the ore carried by aerial or surface tramways to the concentrating plant, but the usual system is to operate from one shaft and hoist from one level. In most mines in the district, no attempt has been made to grade and classify the ore, and choose the ore to be mined at a given time, by blocking out the mine with haulage drifts and crosscuts.

The usual system has been to start at the shaft and mine away from the shaft in all directions showing ore, taking the ore as it comes, and leaving ore only where necessity requires it to be left in the form of pillars.

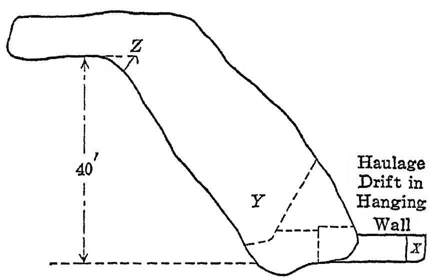


Fig. 22.—Vertical cross-section.

Experience has shown that about 10 per cent. of the ore in the mines of the district has been left in the form of pillars.

Recently several mining companies with large orebodies blocked out have introduced new mining methods to meet existing conditions.

In one case, shown in Fig. 22 and 23, the orebody pitched along the strike and at right angles to the strike. Fig. 22 shows a vertical cross-section and Fig. 23 shows a vertical longitudinal section of the mine. As shown at X in both figures, main haulage drifts were driven along the foot of the pitch of the orebody, and at regular intervals raises were started, and by overhead stoping, orepockets were made into which all of the ore along the pitch up to the top flat Z was broken and drawn at X. The ore in the top flat Z has to be shoveled into cars, and trammed to the edge of the stope and dumped into the pocket below.

In another case the orebody shows considerable variation, vertically and horizontally, in the grade of ore. Fig. 24 and 25 show the method of mining being used at this property.

The orebody averages about 100 ft. (30 m.) width and 60 ft. (18 m.)

height. A main haulage drift X is driven along the foot of the pitch, and about every 250 ft. (76 m.) a crosscut drift Y is driven across the ore-body. In each of these crosscut drifts there are two raises, which will be converted into pockets, and the high-grade ore in the upper half of the mine A will be broken and dumped into these pockets. The lower-grade ore in the lower half of the mine B will be worked out later, on a high market. Each of the stopes C, D, E, F, G and H will be worked in this manner, and the stope to be worked at a given time will depend upon

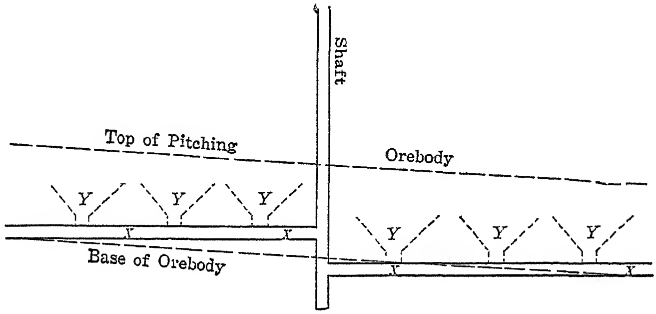


FIG. 23.—LONGITUDINAL VERTICAL SECTION.

the grade of concentrates it will produce and the existing market conditions.

Fig. 26 shows a vertical cross-section of a mine worked on two levels. The part of the stope above the line X–Y was worked out first because the lower part of the stope was mineralized only in the part marked A. In several cases in the district, the heading above the line X–Y has been carried ahead of the lower part of the stope A, and the tracks on the floor

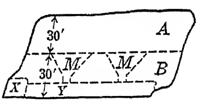


FIG. 24.

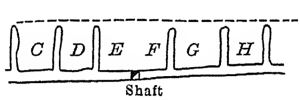


FIG. 25.

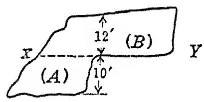


FIG. 26.

of stope B are graded down to the level of the floor of stope A toward the shaft, so that all of the hoisting is done from the level of stope A and mining is carried on simultaneously from both levels.

System of Mining

The usual system of mining is one of underhand stoping, as shown in Fig. 27. The heading is usually carried with a machine drill on a 6 or 7-ft. (1.8 or 2.1-m.) column and when the heading gets 15 or 20 ft. (4 or 6 m.) ahead of the stope the benches are drilled with a machine drill mounted

on a tripod, and broken from top, starting at the top and working toward the bottom. The benches are carried about 10 ft. (3 m.) high. Heading holes are drilled 8 or 10 ft. deep and stope holes are drilled 10, 12 or 14 ft. deep. Three or four holes are usually drilled per round in the heading.

Fig. 28 shows a plan cross-section of a mine heading in which A represents the three machine "set ups" necessary to drill rounds 1, 2, 3 and 4. The heavily shaded portion represents the portion of the heading broken by these rounds, and B, B_1 and B_2 represent the three set ups necessary for breaking the next three blocks of the heading represented by the three lightly shaded blocks.

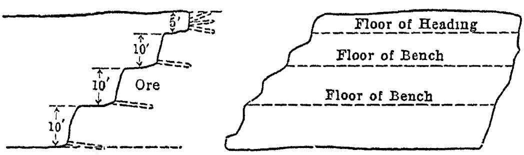


FIG. 27.—LONGITUDINAL VERTICAL SECTION OF STOPE AND HEADING AND VERTICAL CROSS-SECTION OF STOPE AND HEADING.

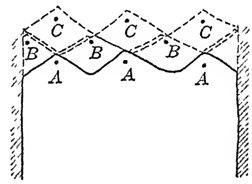


FIG. 28.—PLAN OF MINE HEADING SHOWING POSITION OF DRILL AND HOLES IN BREAKING HEADING.

Drilling

In the earlier use of machine drills in the district, it was frequently customary to drill stope holes straight down at right angles to the bedding planes, but this custom has been entirely abandoned. Stope holes are now drilled horizontally parallel to the bedding planes or pointing down slightly. The ground foreman has to use the best judgment in the placing of holes and the depth of holes to get the best results. The nature of the rock has to be taken into consideration, whether it is hard or soft, compact or loose, or full of crevices and openings. In heading work, a machine man should be able to drill from 50 to 100 ft. (15 to 30 m.) per shift, and in stope work he should be able to drill from 30 to 60 ft. (9 to 18 m.) per shift. In heading work there should be at least 1 ton of rock broken for each foot drilled, and in stope work, sometimes an average as high as 10 tons per foot drilled is reached. An average mine figure would be from 1.5 to 5.0 tons of ore broken per foot drilled, depending upon the height and width of stope and the presence of openings at the top flat of ore in the heading.

Types of machine drills commonly used in the district are the Ingersoll-Rand butterfly-valve piston machine, Sullivan light weight with water attachment, the Wood piston drill, Ingersoll-Leyner hammer machine, and the Ingersoll-Rand jackhamer.

Blasting

The common explosives used in the district are 30, 35 and 40-per cent. blasting gelatine and ammonia nitrate explosives. The explosive comes in boxes containing 50 lb. with 85 to 130 sticks to the box. The explosives are kept in a surface magazine situated at a considerable distance from the mine surface plant. The thawing house is seldom placed less than 300 ft. (91 m.) from the mine buildings.

At most of the mines the machine drillers blow out, load, and shoot the holes they drill. Blasting on the day shift is usually done about 3:30 p.m. and on the night shift about 3:30 a.m. In some of the mines, "boulders" or large, loose fragments of rock broken loose by the previous shift are broken at the lunch hour in the middle of the shift. Some of the mining companies eliminate most of the large boulders and break the rock finer by drilling more holes and using less explosive in each hole. The practice of "squibbing," except in deep stope holes, is disappearing from the district.

After completing drilling for the day, each machine man blows out his holes and loads them by shoving the split sticks of powder into the holes with a wooden "tamping" bar tipped with wood or copper. The cap or detonator is placed in one of the last two or three sticks of explosives placed in the hole. The detonator used is usually a No. 6 or No. 8. After placing all of the explosive in the hole, some companies fill the hole to the collar with a specially prepared tamping, or damp clay or earth. A 50-lb. box of 35-per cent. explosive should break from 40 to 60 tons of ore in heading work, and from 75 to 100 tons in stope work. A general mine average is from 50 to 100 tons broken per box of powder.

Timbering

Very few of the mines require any timber. Some use a few posts to give warning of any settling of the roof, where the pillars are not close, but the roof in most of the mines is a solid thick-bedded limestone. One shallow mine in the district with no solid roof uses the square-set system of mining.

Loading Ore

The ore as broken from the stopes and headings is shoveled into sheet-iron "tubs" or "cans" cylindrical in shape and made in sizes 24 by 24 in. (61 by 61 cm.), 28 by 30 in. (71 by 76 cm.), and 30 by 30 in. (76 by 76 cm.), but where cages are used for hoisting, cars replace the cans. The 30 by 30-in. and 28 by 30-in. cans are called 1000 lb. of ore. Since it takes about 12 cu. ft. of broken ore to weigh 1000 lb., the 30 by 30-in. can probably most nearly represents 1000 lb. of ore, especially since they are not filled level with the top, to increase safety in hoisting.

Most of the loading is done by contract shovelers, who receive 7, 8 or 9 c. per 1000-lb. can, depending upon the distance they have to tram the loaded cans. Most of the contract shovelers are foreign labor, being Bulgarians, Slavs, Poles, and Russians.

Haulage

Several systems of haulage are used. In most of the mines, the cans (placed on ground cars), or the ore cars after being loaded, are shoved or trammed to the shaft by men who do nothing else. In other mines, mule haulage is used for conveying the ore and in several others gasoline locomotives are used for haulage. When the face of ore is not more than 300 or 400 ft. (91 to 121 m.) from the shaft, the contract shovelers convey the loaded ore to the shaft.

Underground rope haulage, electric motor haulage, and compressed-air locomotive haulage have never been attempted in the mines of the district.

Hoisting

Motor-driven or steam-driven geared hoists, or hoists belt-driven by gasoline engines, are used in the district. The latter type is not used in the larger and deeper mines.

The hoist is usually placed on the landing platform of the hoisting derrick when "cans" or skips are used for hoisting the ore, but it is usually placed on the ground when cages are used for hoisting. In the former case, no attempt has been made to balance the load, but in the latter case the cage has been balanced. When a cage or skip is used for hoisting the ore, cars are used underground instead of "cans." When the cage is used the cars are carried to the surface on the cage platform, and when a skip is used the underground cars are dumped into an ore pocket from which it is drawn into the skip.

The hoists in the larger mines are from 35 to 75 hp., make the round trip with hoisting load in 25 to 45 sec., and can handle from 200 to 500 tons per 9-hr. shift. The usual size of hoisting cable used is 5/8 in. (15.9 mm.). The can and tub bails are usually 1¼-in. (31.75-mm.) Norway iron. The cable hooks are 1¼-in. Norway iron. Two types are used in the district, the one a snap hook, and the other the "pig tail" or spiral type.

Power

The larger mines use steam or electric power, while some of the smaller mines use gasoline or oil-engine power. Many of the larger mines use electric power purchased from the Interstate Light and Power Co. of Galena, Ill., or the Mineral Point Light and Power Co. of Mineral Point, Wis.

Most of the mining properties of the district require from 75 to 250 hp. for mining, milling, and pumping operations. The tendency of the district is toward all electric power for mining operations.

Concentrating or Milling

The milling practice of the district in a general way is similar to the methods used in the Joplin, Missouri, lead and zinc district, that is, the ore is crushed and jigged; but in details the process is very different. None of the average Wisconsin mines supplements jigging with the concentration of sands on tables. The usual mill consists of crusher, rolls, one or two jigs and the necessary trommels and elevators.

The mills of the district are housed in frame buildings, placed on concrete foundations. The cost of a mill with all machinery varies from $10,000 to $30,000, depending upon its capacity and equipment.

The usual practice of the district is to build the concentrating plant or mill adjoining the hoisting derrick and hopper, but frequently the ore is conveyed on the surface as much as half a mile from the shaft to the mill. In this case the hopper at the shaft feeds onto a belt conveyor or into surface tram cars or aerial tram buckets or cars, which deliver the ore at the mill hopper.

After the ore is hoisted, it is delivered onto a grizzly above the hopper, of which the bars are spaced from 4 to 6 in. (10.16 to 15.24 cm.) apart. The oversize is either sorted by hand, the pieces containing ore being broken by sledge hammers to pass through the grizzly bars and the waste rock being loaded into cars and dumped on the surface outside the hopper, or it is all fed to a large crusher, which breaks all of the large pieces of rock and ore and discharges them into the hopper.

From the hopper, which usually has a capacity of 100 to 200 tons, the ore is fed directly into a 14-in., 18-in. or 24-in. (35.6, 45.7 or 61.0-cm.) crusher of the Blake type, or onto a shaking screen. In the latter case, the fine material passes through the skaking screen and goes direct to the first rolls, and the coarse material or oversize is fed to the crusher.

The material from the crusher runs down an inclined trough to the first rolls, usually 24-in. (61-cm.), 30-in. (76-cm.), 36-in. (91-cm.) or 48-in. (122-cm.) rolls of the Cornish type. The crushed material from these rolls is carried in an incline trough to the dirt elevator. The dirt elevator feeds into a trommel with 3/8-in. (9.5-mm.), 1/4-in. (6.35-mm.) or 5/8-in. (15.9-mm.) perforations. The oversize from the trommel is fed to the second rolls, usually 24 or 30 in. (61 or 76 cm.), of the Cornish type, and from these rolls it is returned to the dirt elevator.

The undersize product from the trommel is fed onto the rougher jig, in a two-jig mill, or onto the combined rougher and cleaner jig in a one-jig mill. Up to this point the process is the same in the one- and two-

jig mills, but from this point the processes are different and will be described separately.

One-jig Mills

The jig, usually of the Cooley type, consists of 7, 8 or 9 cells, each cell usually with a 30 by 36-in. (76 by 91-cm.) jigging area on each cell.

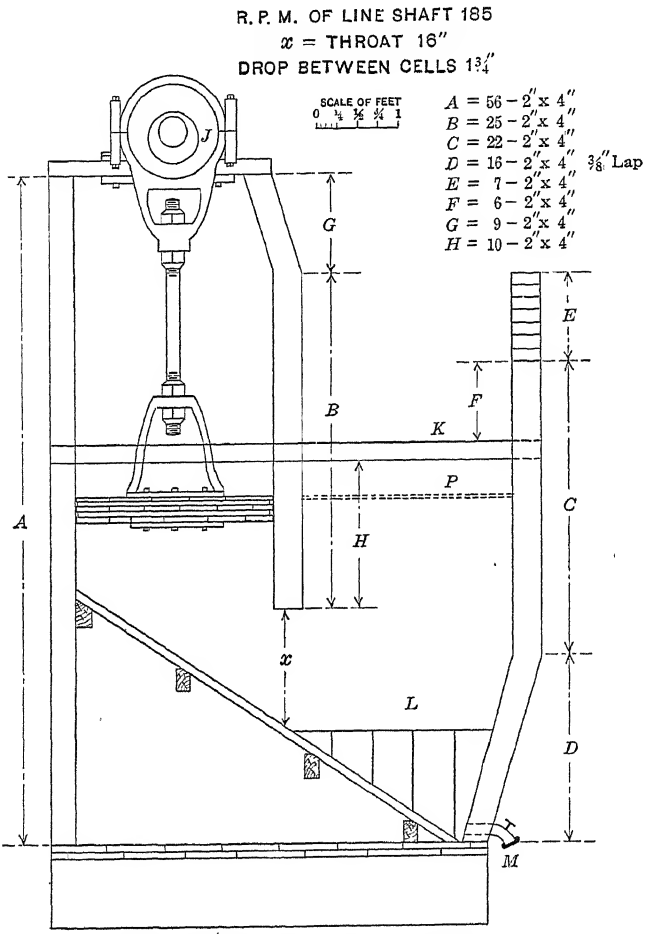


FIG. 29.—CROSS-SECTION OF 7-CELL JIG.

A common pitch from cell to cell in a jig having 30 by 36-in. cells is 1¾ in. (44.5 mm.) per cell. The amount of water used in milling varies from 800 to 1200 gal. per minute.

Cell 1 is used for cleaning lead, and cells 3, 4 and 5 are used for cleaning zinc in the 7-cell jig, and cells 3, 4, 5, 6 and 7 are used for cleaning zinc in the 9-cell jig. Mixed lead and zinc product from cell 2 is either returned to the dirt elevator or the chat elevator. The product from

cells 8 and 9 in the 9-cell jig and cells 6 and 7 in a 7-cell jig are sent to the chat elevator. From the chat elevator the material is sent to the chat rolls, usually of 24-in. Cornish type.

The crushed material from the chat rolls is returned to the dirt elevator. In some one-jig mills there are no chat rolls, and in this case the "chat" material is fed to the second rolls with the oversize from the trommel. This "chat" material is undersize material from the trommel, which accumulates in the second rolls when the fragments are composed of lead and iron sulphides or of lead and zinc sulphides (being heavier than zinc sulphide and lighter than lead sulphide) and accumulates in the last two cells when the fragments are composed of mixed zinc and iron sulphide with lime (limestone), being lighter than zinc and iron sulphides.

Recrushing is necessary for this material in order to free the zinc and iron sulphides from the lead sulphides, and to free the zinc and iron sulphides from the limestone. The material that passes over the lower end of the jig (the tailboard) to the dewaterer carries from 4 to 6 per cent. metallic iron as iron sulphide and from 1 to 2 per cent. metallic zinc as zinc sulphide. This material is carried from the dewaterer at the end of the jig to the tailing elevator, from which it is discharged through a trough to the ground at some point near the mill.

A common size for the sieves or grates on cells 1, 2 and 3 is usually ¼-in. (6.35-mm.) perforation, on cells 4 and 5, ¼-in. perforation, and on cells 6, 7, 8 and 9, 3⁄16-in. (4.763-mm.) perforation.

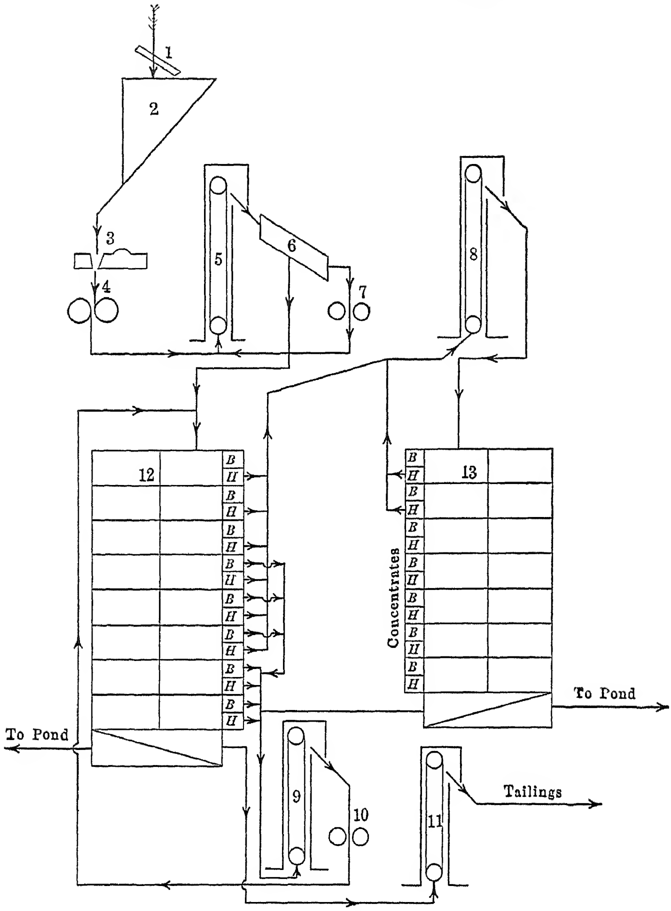
In Fig. 29, *K* shows the sieve or grates, *L* is the hutch or part of the cell below the sieve, *M* is the spigot for drawing from the hutch, *N* is the spigot for drawing from the bed or the part above the sieve, and *P* the jig plunger compartment.

In the one-jig mill, concentrates are drawn from the spigots *M* and *N* in the cells that are used for cleaning ore.

Two-jig Mills

The two-jig mill process is practically the same as the one-jig mill process up to the point of the delivery of the undersize product to the jig. The two-jig mill has a rougher jig with from 5 to 9 cells, usually with a 30 by 36-in. (76 by 91-cm.) jigging surface on each cell, and a cleaner which has from 5 to 7 cells of the same size. For convenience of description, I will take the case where the rougher and the cleaner each has 7 cells.

A common construction in the jigs of a two-jig mill of this type is as follows: the sieves or grates in the first 5 cells of the rougher have ⅛ in. (3.2-mm.) perforation and the sixth and seventh cells 1⁄12-in. (2.1-mm.) perforation, the first three cells of the cleaner have 1⁄16-in. (1.6 mm.) perforations and the last 4 cells 1⁄12-in. perforation.



1 Grizzly 8 in. 2 Hopper 200 Tons 3 Crusher 15 in. 4. First Rolls 36 in
5 Dirt Elevator: Height 20 ft., Size 20 in , Cups 20 in. × 6 in.
6. Trommel 36 in × 72 in , Opening ⅜ in.
7. Second Rolls 24 in
8. Smittem Elevator: Height 15 ft., Size 12 in , Cups 12 in. × 6 in.
9. Chat Elevator. Height 20 ft., Size 12 in , Cups 12 in. × 6 in.
10. Chat Rolls 24 in.
11. Tailing Elevator: Height 60 ft., Size 12 in., Cups 12 in. × 6 in.
12. Rougher Jig 30 in. × 36 in. 8-Cell

Cells	Speed	Screen	Stroke	Depth of Bed	Pitch of Bridge	Plunger Level
1	144	No 12 grate	1¼	6 in.	¾	Level
2	"	" " "	1¼	"	"	"
3	"	" 8 "	1¼	"	"	"
4	"	" " "	1¼	"	"	"
5	"	" " "	1¼	"	"	"
6	"	" " "	1¼	"	"	"
7	"	" " "	1¼	"	"	"
8	"	" " "	1¼	"	"	"

13. Cleaner Jig 30 in. ×36 in., 7-Cell

Cells	Speed	Screen	Stroke	Depth of Bed	Pitch of Bridge	Plunger Level
1	195	1/16 in.	¾	6 in.	¾	Level
2	"	"	"	"	"	"
3	"	3/16 in.	"	"	"	"
4	180	"	"	"	"	"
5	"	"	"	"	"	"
6	"	"	"	"	"	"
7	"	"	"	"	"	"

FIG. 30.—FLOW SHEET. WINSKELL MINE.

In the two-jig mill process, the undersize is fed to the rougher, which has from 5 to 9 cells, usually with a 30 by 36-in. jigging surface. The oversize or sieve product on the middle cells of the rougher is cleaned and drawn from the spigot *N* when the product is not "chatty."

When the ore is "chatty," it is drawn and taken to the chat elevator, and from there to the chat rolls, from where it is returned to the dirt elevator. Fig. 30 shows a flow sheet of a typical two-jig mill. In case the "sands" are not treated, this product is run into the tailing elevator, instead of to the sand elevator, as shown in Fig. 30.

The hutch product from the rougher, the "smittem," is carried to the "smittem" elevator and from there to the cleaner jig, where it is cleaned.

The finished lead concentrate is drawn from the hutch of the first cell of the cleaner. The hutch or middling product from the hutch of the second cell is returned to the smittem elevator. The hutch product from the third, fourth, fifth and sixth cells is finished zinc concentrates. The hutch product from the seventh cell when not "chatty" is returned to the smittem elevator, but when "chatty" is returned to the chat elevator. The material passing over the tailboard of the cleaner jig is sent to the tailing elevator, unless the sands are to be treated on a sand jig, and in that case it is taken to the sand elevator; or when the cleaner tailings contain considerable zinc they are returned to the dirt elevator or to the chat elevator.

Three varieties of jig screens are used in the district, namely, perforated sheet steel, jig grates, and woven wire screen cloth. The first of these is most commonly used, it being claimed that it has the advantage over grates, that no "dead beds" exist, because of the greater perforation area, producing better and more uniform pulsation on the beds. This enables the ore to be cleaned more thoroughly, and is especially advantageous in keeping down the lime and lead content of the zinc concentrates. It is also claimed that perforated metal (sheet steel) adapts itself better to a variable feed to the jig. Grates have the advantage over perforated sheet steel and woven wire screens, that the bed does not have to be cleaned so often.

Roasting or Calcining Ores

A feature of the district is the roasting or calcining and magnetic separation of low-grade zinc ores.

The Mineral Point Zinc Co., at Mineral Point, Wis., has a Skinner roaster, which calcines about 1500 tons of green zinc concentrates per week. The calcined concentrates are then treated on a Rowand-Wetherill magnetic separator, which removes the magnetic iron sulphide, producing a finished zinc concentrate assaying from 57 to 59 per cent. metallic zinc. The fumes from the calcining process are used at this plant for the manufacture of sulphuric acid.

The Wisconsin Zinc Co. has a Skinner roaster at New Diggings, similar to the one of the Mineral Point Zinc Co. at Mineral Point, but at this plant the fumes produced in calcination are not used for the manufacture of sulphuric acid, and Cleveland-Knowles separators are used for the separation of the calcined concentrates.

The National Separating Co. has a plant with four roasting kilns of the Mathey type located at Cuba City, Wis. This plant is equipped with Dings magnetic separators and has a capacity of about 1000 tons of "green" concentrates per week.

The Campbell Magnetic Separating Co. has a plant with four roasting kilns of the Campbell type, located at Cuba City, Wis. This plant is equipped with Campbell separators and has a capacity of about 300 tons of "green" ore per week.

The Linden Zinc Co. has a plant with two roasting kilns of the Campbell type, located at Linden, Wis. This plant is equipped with Campbell magnetic separators and has a capacity of 150 tons of "green" ore per week.

There are also several roasting plants of the Mathey type at different mines in the district, and two custom roasting plants of this type near Galena, Ill., not operating.

The roasting or calcining process consists of heating the ore in the kiln, which has a continuous feed, by coal or oil in an adjoining firebox. Coal is used in the Mathey roaster and oil is used in the Campbell roaster. In the Skinner roaster, the marcasite in the ore furnishes the fuel. The sulphur in the ore aids in the combustion. Only the outer crust of the fragments or particles of marcasite or pyrite are changed by the heat to a magnetic sulphide, which, after the ore is discharged from the kiln, cooled and fed to the magnetic separating machines, is picked out of the feed of mixed zinc and iron sulphides by the magnets and is discharged as a tailing product.

The feed to the roasting kiln usually assays from 20 to 40 per cent. metallic zinc. The finished ore from the magnetic separators assays from 58 to 61 per cent. metallic zinc. The tailings from the magnetic separators assays from 3 to 8 per cent. metallic zinc.

Ore-buying Companies

All of the companies named in the previous paragraph as operators of magnetic separating plants, buy ore running from 20 to 40 per cent. metallic zinc for their roasting plants, in addition to what is roasted from their own mines.

In addition to these companies, a number of the zinc-smelting companies have buyers in the district. These buyers purchase high-grade ores from the mines and the roasted ore product from the separating plants.

The smelting companies that have ore buyers in the district are the

Mineral Point Zinc Co. with a smelter at DePue, Ill.; the Grasselli Chemical Co. with smelters at New Castle, Ind., New Castle, Pa., Clarksburg, W. Va., and Meadow Brook, W. Va.; the Matthiessen & Hegeler Zinc Co. with a smelter at LaSalle, Ill.; the Illinois Zinc Co. with a smelter at Peru, Ill.; the American Zinc & Chemical Co. with a smelter at Langeloth, Pa.; and the American Zinc Co. of Illinois with a smelter at Hillsboro, Ill.

The Illinois Zinc Co. and Matthiessen & Hegeler Zinc Co. buy zinc concentrates low in lead, because much of their spelter product is rolled into sheet zinc. The Grasselli Chemical Co. buys zinc concentrates low in lead because they make a high-grade spelter for the brass and bronze trade. The other smelting companies are not so particular about the lead content of the zinc concentrates because they make Prime Western spelter for galvanizing purposes.

The buyers for the smelting companies purchase on a base of 60 per cent. metallic zinc contents in the zinc concentrates. They penalize $1 per unit of zinc below 60 per cent. and pay a premium of $1 per unit above 60 per cent. Iron is penalized at the rate of $1 per unit over 1 per cent.; lime is penalized $0.50 per unit over 2 per cent.; lead is penalized $1 per unit over 1 per cent. This scale of penalties and premiums usually applies to concentrates containing from 50 to 63 per cent. metallic zinc. For ores of a lower grade a different scale is used.

Some ores are purchased on contract deducting a fixed smelting charge from the value of the metallic zinc content of the concentrates.

Operating Mining Companies of the District

Three-fourths of the production of the district is made by five companies. The following list gives the principal operating mines of the district, their location and the name of the operating company.

Mine	Location	Company
Coker	Livingston, Wis.	Mineral Point Zinc Co.
Highland	Highland, Wis.	Mineral Point Zinc Co.
New Coker	Livingston, Wis.	Mineral Point Zinc Co.
Penna Benton	New Diggings, Wis.	Mineral Point Zinc Co.
Hoskins	New Diggings, Wis.	Mineral Point Zinc Co.
Fox	Hazel Green, Wis.	Mineral Point Zinc Co.
Kennedy	Hazel Green, Wis.	Mineral Point Zinc Co.
Black Jack	Galena, Illinois	Mineral Point Zinc Co.
Yewdell	Livingston, Wis.	Vinegar Hill Zinc Co.
Martin	Benton, Wis.	Vinegar Hill Zinc Co.
Kittoe	Benton, Wis.	Vinegar Hill Zinc Co.
North Unity	Day's Siding, Ill.	Vinegar Hill Zinc Co.
Graham	Galena, Ill.	Vinegar Hill Zinc Co.
Blackstone	New Diggings, Wis.	Vinegar Hill Zinc Co.
Meloy	New Diggings, Wis.	Vinegar Hill Zinc Co.
Winskell	New Diggings, Wis.	Wisconsin Zinc Co.
Champion	New Diggings, Wis.	Wisconsin Zinc Co.

Mine	Location	Company
Longhorn	New Diggings, Wis.	Wisconsin Zinc Co.
C. A. T.	New Diggings, Wis.	Wisconsin Zinc Co.
Frontier-Calvert	Benton, Wis.	Frontier Mining Co.
Bull Moose	Benton, Wis.	Frontier Mining Co.
Hird	Benton, Wis.	Frontier Mining Co.
Middie	Benton, Wis.	Frontier Mining Co.
Treganza	Benton, Wis.	Burr Mining Co.
Cleveland	Hazel Green, Wis.	Cleveland Mining Co.
Lawrence	Hazel Green, Wis.	Cleveland Mining Co.
Block House	Platteville, Wis.	Block House Mining Co.
M. & A.	Livingston, Wis.	M. & A. Mining Co.
Biddick	Livingston, Wis.	B. M. & B. Mining Co.
Optimo	Linden, Wis.	
Lucky Six	Mifflin, Wis.	
Squirrel	Mifflin, Wis.	B. M. & B. Mining Co.
Mulcahy	Shullsburg, Wis.	Oliver Iron Mining Co.

This list contains only about half of the properties that have produced ore during the past year, and does not contain the names of any properties not equipped with a milling plant, but it does include the names of all of the big producers of the present time in the district.

Summary

The mines of the district are widely scattered, most of them being a mile or more from any other mine. Prospecting is being carried on largely by the big companies, with good results.

The production of the district grew from 19,000 tons of concentrates in 1904 to 220,000 tons in 1916.

Taking into consideration the scattered nature of the ore deposits, the size of the district, and the number of mines that have been found with a small amount of prospecting, it is safe to predict a steady growth, a long life, and a bright future for the Wisconsin Zinc District.

DISCUSSION

W. O. Hotchkiss, Madison, Wis. (written discussion*).—Mr. George's paper on "The Wisconsin Zinc District" is a very complete and clear description, which it is a pleasure to read. His discussion of the origin of the ores is the least satisfactory part, and Mr. George correctly states present knowledge when he begins his paragraph on origin with the words "the general supposition is, etc." There is still much to be learned regarding the details of the processes by which the ores have reached their present situation. In this the Wisconsin district differs not at all from other mining districts. It is my hope that Mr. George and others, equally clear-thinking, who are in close touch with these operations will be able at an early date to give us more information on this subject.

* Received Jan. 17, 1918.

The paper states that to the present time exploration has been guided almost wholly by the surface lead diggings of the early days, that most of these have now been prospected, and that future discoveries must come from drilling, guided by the geologic factors which have caused the concentration of the ore. Successful exploration will be greatly assisted by further study, and by discovering and presenting new factors.

The section of the paper dealing with "Estimates of Values" brings to mind our experiences in valuing these mines for purposes of assessment. In 1913 the legislature directed the State Geological Survey to "make an accurate determination of the amount of ore therein, the expense of mining, the probable life of the mine, and such other factors as may be necessary, in the judgment of the State Tax Commission and the Geological and Natural History Survey, for a proper valuation thereof." The attempt was made for one year to value these properties in the way, familiar to many of you, that the iron mines of Michigan and Wisconsin are valued. I assigned my assistant, W. L. Uglow, to this work and we made a very thorough study of the conditions, the results of which appeared as a *Survey Bulletin* by Mr. Uglow on "Mine Valuation and Assessment." It was soon discovered that some of the necessary factors in such a valuation were lacking, because of the general practice of drilling an orebody only to a sufficient extent to show enough ore to justify the expenditure for erecting a mill and sinking a shaft. The shape and size of the orebodies make this the most economical procedure, and the result is that large prosperous mines frequently have but a few months' supply of ore blocked out. As a problem in taxation the situation was further complicated by the general leasing custom under which the farmer who owned the fee to the land and the ore paid the taxes. After long and careful study of various methods of mine taxation, and the average conditions in this district, a method of assessment was devised which was put into effect by the legislature of 1915. Under this the assessment is determined by adding to the agricultural value of the parcel of land one-fifth of the gross sales for the preceding calendar year. This operates to take for taxes only about 2 to 4 per cent. (depending on the local tax rate) of the 10-per cent. royalty which the land owner receives (0.2 to 0.4 per cent. of the gross production) and is not a heavy burden as real-property taxes go. In addition to this—which is construed as a real-property tax—the land owner pays his State income tax, as on all other non-exempt income.

W. N. Smith, Platteville, Wis. (written discussion*).—

Milling Practice

Mr. George mentions the fact that practically none of the Wisconsin mines supplements jig concentration with separation of the fines on sand

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* Received Jan. 19, 1918.

or slime tables. This fact will undoubtedly seem strange to operators who are not familiar with the character and occurrence of the ores of this district; but there is a reason. In the first place, the percentage of lead concentrates recovered by the average mine is too small to warrant the installation of tables to recover the fine lead. At times, and locally, the percentage of lead accompanying the zinc ores is high, but this seldom, if ever, occurs for a long enough period to be of sufficient importance to install equipment to save the lead fines alone.

In the crushing and concentration of the zinc ores, a considerable percentage of the zinc sulphide is reduced to sand and slime. In practically every mine in the district, however, there occurs with the zinc sulphide a constant and high percentage of iron sulphide in the form of marcasite. This marcasite breaks down much more readily than does the zinc sulphide, so that even at mines where the jig concentrates assay high enough to be shipped direct to the smelter, the concentrate recovered on sand or slime tables contains so high a percentage of iron sulphide that if it were mixed with the jig concentrates it would lower their grade so greatly that the penalties would overbalance the value of the table concentrates. No table practice yet tried in the district has been able to separate the iron sulphide from the zinc sulphide.

As stated by Mr. George, the common practice in the district, for treating concentrates which contain too high a percentage of iron sulphide, is to give this green concentrate a skin roast which makes the iron sulphide magnetic and allows it to be separated from the zinc sulphide magnetically, making a clean high-grade zinc product and an iron-sulphide product which contains enough sulphur to be shipped to sulphuric-acid plants. In this roasting process, however, on account of the draft, there is a loss, estimated at 3.50 per cent., of zinc in the form of fine particles which escape through the stack. At a number of mills where concentrating tables have been operated, the table concentrates have been treated in the roasters, but it has been found that so high a percentage of this fine product is lost through the stacks that the net result showed no profit in operating the concentrating tables.

At the present time it seems probable that the loss of zinc fines in this district can best be prevented by flotation treatment. Several companies have been experimenting along this line, with encouraging results, although, so far as I know, the problem has not yet been entirely solved. In flotation treatment of the ores of this district there must be, in the first place, a separation of the sulphides from the gangue. The major portion of the gangue is dolomitic limestone, from which it is not difficult to separate the sulphides; but at the base of the dolomitic limestone, as described by Mr. George, occurs a carbonaceous shale, locally called oil rock, and it has been found difficult to separate the sulphides from both the dolomitic limestone and the oil rock by the same operation. In addition

to this difficulty, there is also the necessity of making a clean separation between zinc sulphide, iron sulphide, and lead sulphide. The lead sulphide can probably be separated satisfactorily on tables, if necessary, but as the iron and zinc sulphides have practically the same specific gravity they will not separate on tables. Therefore, the problem seems to be to develop a preferential flotation process which will separate the iron and zinc sulphides from each other, as well as from the carbonaceous gangue.

Underground Power Shovels

During the past 2 years, on account of the shortage of labor and increasing mining costs, attempts have been made at several mines to in-

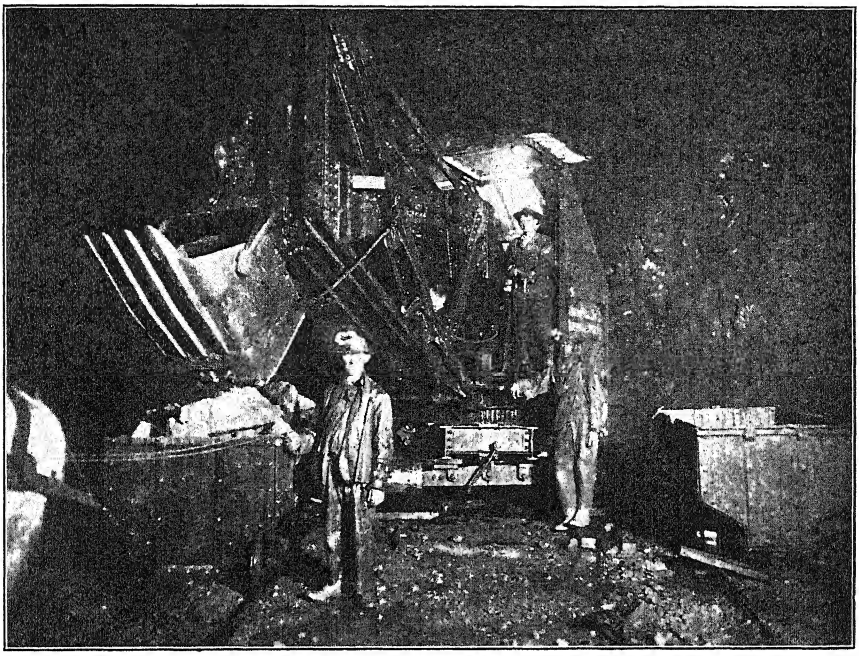

Fig. 1.—Thew shovel in Meloy mine, Wisconsin.

troduce mechanical shovels. The most successful attempt was at the Meloy mine in the New Diggings district. The shovel there used is the special mining type built by the Thew Automatic Shovel Co. It is simply an adaptation of the standard steam shovel built to operate in a small space, driven by a 20-hp. electric motor, and designed to be operated by one man. It will work in a room 16 ft. square. The shovel, as used at the Meloy mine, is mounted on traction wheels and can be readily moved from one stope in the mine to another, although if the stopes of the mine were more than 500 ft. apart it would probably be better to use two

shovels than to move one, unless the stopes were large enough to permit the shovel to operate at least two days in each stope. In the Meloy mine the stope is just large enough for the shovel; consequently, the tonnage of mine rock which can be broken each day in that stope is not nearly as great as could be handled by the shovel. However, during the past three months, the shovel has handled an average of 112 tons per 9-hr. shift at a total cost of 11.4 c. per ton, as compared with a cost of 19 c. per ton for shoveling and loading the same kind of dirt, in the same mine, by hand. Furthermore, previous to the operation of the shovel, it was not possible to load more than 75 tons per shift by hand from the same stope, on account of limited room and the sticky character of the mine dirt. The crew of the Thew shovel comprises a shovel operator, a pitman, and a mule driver. The shovel loads into cars of 1.5-ton capacity, which are hauled to the shaft by mules and hoisted on self-dumping cages.

The shovel easily cleans up in half a shift all the dirt which can be broken on this stope each day. At various times the mine dirt has been allowed to accumulate, and it has then been demonstrated that the shovel can handle 225 to 250 tons per shift; in that case, of course, the cost per ton is materially lower than the figure above given, and lower than has ever been accomplished by hand shoveling, even under the most favorable labor conditions. The shovel has the ruggedness and simplicity of the ordinary steam shovel, which is a very important factor.

Notes on the Disadvantages of Chrome Brick in Copper Reverberatory Furnaces

BY FRANCIS R. PYNE,* EL. MET., CHROME, N. J.

(New York Meeting, February, 1918)

The following notes are presented in an endeavor to point out the disadvantages attending the use of chrome brick in reverberatory furnaces in which are conducted the treatment of materials of such a nature that absorption by the brick is of too great value to be wasted, and these values must be recovered, if possible, in order to prevent metal losses that can not be tolerated.

Several years ago one of the large Eastern copper refineries decided to utilize basic material in place of siliceous material in the walls of their reverberatory furnaces for the treatment of very foul blister copper, as the latter rapidly corroded the siliceous linings. It was also expected that there would be less slag formation, with a consequent decrease in the cost of treatment and a reduction in the metal losses.

Magnesite brick were first used, but while the corrosive action of the foul material was greatly reduced, and the amount of slag formed was very much less, the magnesite proved to be unsatisfactory in certain parts of the furnace, because of its tendency to crack and spall badly when subjected to the alternate heating and cooling that takes place in a reverberatory refining furnace. This made many repairs necessary, and consequent frequent interruption in the operation of the furnace, which, together with the high price of the magnesite brick, ran up the cost of maintenance to an unreasonable amount.

It was, therefore, decided to substitute chrome brick for magnesite brick in the parts of the furnace affected. The results, as far as the reverberatory furnace was concerned, were very satisfactory. The corrosion due to the action of the foul blister was small and the amount of slag formed was no greater than when using magnesite, and the tendency to crack and spall shown by the magnesite was eliminated. Gradually the use of chrome brick was extended to all furnaces, those treating blister copper as well as those melting cathodes, and the results were so satisfactory that the siliceous roofs were replaced by roofs of chrome brick except in certain places where experience showed a more satisfactory performance on the part of the silica brick.

It was immediately recognized, for both the magnesite and the chrome brick, that the metal absorption was very heavy, but it was felt that the

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longer life of the furnaces and the decreased cost of slag treatment and metal losses would more than offset this disadvantage.

When repairs had to be made to the furnaces, the resulting cobbing was sent to the blast furnaces for the recovery of the copper, silver and gold contents. It was, of course, realized that chrome was a neutral material and could not be fluxed, but it was thought that, at the blast-furnace temperature, the cobbing would be melted, releasing the locked-up values and causing the chromium oxide to pass out mixed with the blast-furnace slag.

For a time this method appeared to be satisfactory, but as more of the cobbing was made and treated in the blast furnaces, trouble developed. The capacity of the settlers began to be seriously reduced and slag losses increased, due to improper settling. On investigation, it was found that there had formed in the settler, between the matte and the regular slag, a layer of thick, mushy slag which was causing the trouble.

This mushy slag could not be fluxed, could not be tapped out with the matte, and would not of itself overflow through the slag spout. The only way it could be removed from the settler, without shutting down and digging it out, was to insert a pipe into the layer and by the use of compressed air cause it to mix and overflow with the regular slag. While this procedure cleaned out the settler, it also resulted in metal losses that could not be tolerated. Samples of this mushy slag showed it to contain as high as 25 per cent. chromium oxide, indicating that the cause was in the chrome cobbing added to the charge. Upon discontinuing the treatment of the cobbing, the settler trouble disappeared. The natural result of this was to accumulate a considerable stock of the chrome cobbing, and experiments were undertaken to devise a satisfactory process for the removal of the values that would leave a residue that could be sent to the dump.

The cobbing was crushed fine, thereby releasing the larger metallic particles, and treated in a reverberatory furnace with roasted pyritic ore and silica. This treatment gave a fairly fluid slag in which the chromium was apparently soluble. A considerable amount of the metal values was thus recovered, but the slag was still too rich in copper to throw away, and when sent to the blast furnaces, induced a return of the former settler troubles.

Fine crushing and fusion with a very low-grade matte was expected to remove the values and leave a slag sufficiently low in copper to be discarded. The results were unsatisfactory, for though the matte absorbed much of the values, yet the slag was thick and pasty and contained considerable copper.

It was felt that crushing followed by mechanical concentration might result in separating the metal from the brick. Accordingly, the material was crushed and screened to remove the coarse metallics and was then

treated on a Wilfley table. There was sizing, but little concentration, as it was found that the entire structure of the brick was saturated with very finely divided copper and copper oxide.

Flotation was also tried without success as the concentrate was too rich in chromium and there were too many values in the residue.

The most satisfactory solution yet found for the disposal of this material is to grind it, thereby freeing the larger metallic particles, and utilize the fine material in the manufacture of refractory brick, thus using the cobbing over and over again. There is, of course, some slagging action and a certain amount of chromium goes to the blast furnace where the mushy slag is formed, but in small amounts it is easily taken care of, and eventually the accumulated stock will be "worn out" and sent to the dump. There are also possibilities of treating this material by converting it into ferrochrome or by making chromate salts.

This experience suggests that chrome brick is not very desirable for this class of work, and that magnesite should be used if possible. Experiments indicate that the tendency of the magnesite to crack and spall can be overcome by subjecting the brick to pressure before burning, which should also cause less metal absorption. There is also no difficulty in treating the cobbing in the blast furnace.

DISCUSSION

H. O. Hofman, Boston, Mass (written discussion*).—The paper by Mr. Pyne gives clear evidence of the difficulties the metallurgist is likely to encounter when he tries to recover in the blast furnace the metal from old chromite lining used as a refractory material in the copper reverberatory furnace. It appears that chromite cannot be fluxed at temperatures which usually prevail in copper blast furnaces. This calls to mind the freezing-point curve drawn by M. Simonis[1] of mixtures of chromite and kaolinite. The chromite used in the experiments contained 52.9 per cent. Cr_2O_3, 22.6 FeO, 4.8 Al_2O_3, 9.6 SiO_2, 10.1 MgO; the kaolinite was clay from Zettlitz with 98.5 per cent. clay-substance. The curve (Fig. 1, p. 154) shows that the eutectic mixture with 35 per cent. kaolinite and 65 per cent. chromite freezes at Seger cone No. 15 (1435° C.), while kaolinite fuses at cone No. 35 (1770° C.) and chromite at cone No. 42 (2000° C.). The curve indicates that the difficulty in the blast furnace can be overcome by having at the smelting zone a temperature much higher than is usual in copper smelting; a charge composition similar to that prevailing at the Mansfeld copper smeltery —which gives with 23 per cent. coke a slag of the composition SiO_2, 49.09; (FeMg)O, 5.58; (CaMg)O, 16.02; Al_2O_3, 16.02—might flux and fuse chromite.

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* Received Dec. 26, 1917.

[1] *Stahl und Eisen* (1908), **28**, 335.

The Chairman (G. H. Clevenger, San Francisco, Cal.).—I would like to ask Mr. Pyne if he has had any experience in the use of chromite as refractory under conditions that are highly reducing? I am reminded of an experience I once had with an electric furnace. I imagined that chromite would form a splendid lining, but it soon disappeared; hence it seems probable that, under highly reducing conditions at a high temperature, chromite is a very poor refractory.

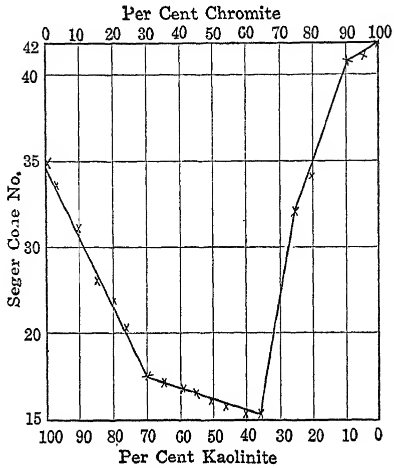

Fig. 1.—(See discussion on p. 153).

F. R. Pyne.—In copper smelting the atmosphere is generally neutral, or slightly oxidizing; we do not use highly reducing atmospheres at all, not even in the matting furnace.

You can take the chromite brick and treat it as you would an iron ore, obtaining ferro-chrome very readily, from which the copper will separate. We have done this; in fact, at one time we considered installing a small electric furnace for the production of ferro-chrome.

Forest Rutherford, New York, N. Y.—During the time I was general superintendent at the smelter of the Copper Queen Consolidated Mining Co., at Douglas, Ariz., a great many experiments were made on the furnaces and settlers with different kinds of brick, and I agree with Mr. Pyne's statements about chrome brick. Their power to absorb metals is very great, and as they cannot be smelted at any temperatures obtainable in a copper furnace, to get rid of the bats and extract the metal from them is quite a problem.

We finally got down to using chrome brick only for lining the settlers, out of which we often got a life of upwards of 2 years, and for lining the blast-furnace bottoms, for the reason that chrome brick can be heated and wet, or wet after being heated, without going to pieces, whereas under these conditions magnesite brick will break down very rapidly.

We also used a layer of chrome brick above and below an 18-in. band of magnesite brick put on the slag line of the reverberatories, in order to separate the magnesite from the silica brick, fearing that they would slag each other and let the wall drop. The idea worked, but became unnecessary on account of a change made in the method of feeding the furnaces.

Chrome brick will not stand up under pressure so well as a good Grecian or Austrian magnesite brick, on account of the poorer bonding properties of the materials from which the chrome brick is made.

On account of the difficulty of obtaining chrome brick since the United States went into the war, two settlers were lined with bauxite brick, which, as far as I have heard, are still in use and the brick is proving satisfactory.

Experiments were also made with magnesite brick on the side walls, in the center drop holes, and in the arches of the reverberatory furnaces, but failed in every case, as magnesite brick, no matter how dense, will not stand moisture or sudden changes of temperature. They spall very badly under these conditions and the wall or arch soon comes down.

The new method, now generally adopted, of feeding reverberatory furnaces along the side walls has simplified the brick problem in furnaces of this kind very much, and a straight silica-brick wall seems to be the best.

Bradley Stoughton, New York, N. Y.—It will be a patriotic act at the present time, especially for the non-ferrous metallurgists, not to use any more chrome brick or purified chrome ore than they absolutely have to use. There is a shortage of that material in this country and the authorities are a good deal concerned about it. For certain purposes chrome brick are indispensable, but wherever it is not essential it is patriotic to get along without it.

Fine-grinding and Porous-briquetting of the Zinc Charge

BY WOOLSEY MCA. JOHNSON, HARTFORD, CONN.

(New York Meeting, February, 1918)

THE object of this paper is to describe the several necessary characteristics of the zinc-retorting charge and to show how by certain improved methods, the large excess of coal, over that theoretically required, can be reduced, thereby effecting an increase in the smelting capacity of a retort plant as well as other economies.

In the southwestern zinc works a charge of roasted zinc ore with a side mixture of carbonates and silicates, analyzing on the average 50 per cent. Zn, is mixed with 55 or more per cent. of its weight of a mixture of coal and coke analyzing 60 to 70 per cent. fixed carbon. The ore is of varying fineness and the coal and coke are usually crushed in a semi-moist condition through a 3/8-in. screen. With ores of a slaggy nature, this coal proportion is increased, sometimes to as much as 100 per cent. of the weight of the ore. With carbonate ores, or where anthracite screenings with higher carbon content are cheap enough, the percentage of reducing agent is cut to 45 per cent. or even somewhat lower. The average charge per retort for a monthly run of a plant on ore, as distinguished from retorts on blue-powder, ladle-skimmings and other between-products, runs from 60 to 66 lb., with a mean of 63 lb. for the Southwest with standard retorts of 8½-in. inside diameter and 50 in. long inside, using roasted sulphide ores. Conditions will change these figures, but 40 lb. of ore per cubic foot of retort space is, I believe, an average in the better-operated plants. Since the rise in the price of spelter, the tendency has been to overcharge. To remove the slag that is formed when retorts are overcharged, extra men are put on to "gum-chisel" the retorts to prevent "set" furnaces and "butchered retorts."

Taking the above conditions as premises, we find that from four to six times the amount of coal necessary for the reduction is used, as is evidenced by the fact that the residues analyze as high as 35 per cent. fixed carbon. There are good reasons why this excess of fixed carbon must be used and perhaps these can be best explained by a description of the metallurgical requisites of a zinc charge. We may enumerate these as follows:

1. High reducing power, especially at the end of the shift, to reduce any carbon dioxide to monoxide and bring about a good condensation

of the vapor. It is, of course, well known that carbon dioxide, if formed in the retort, oxidizes the zinc vapor at lower temperatures and is the cause of the formation of an excessive amount of blue-powder.

2. Heat conductivity as high as possible, so as to permit the heat, as soon as it permeates the walls of the retort, to flow to the inside of the charge in order that as uniform a temperature as possible may be attained in the retort. For this reason large pieces of coal, ore, and coke are charged, since fine material is a poor conductor of heat.

3. Porosity.—If the charge be too dense, the back pressure of the gases produced is so great that the reduction is hindered. Moreover, the porosity allows the secondary gaseous reduction to proceed:

$$ZnO + CO = Zn + CO_2$$
$$CO_2 + C = 2CO$$

4. The charge must leave a residue that is substantially non-slagging in character. Since carbon is infusible, this can be attained by having sufficient fine carbon present in the charge, to leave particles of carbon in the residue. Since the fine particles are predominantly consumed or oxidized in the reduction of the ZnO, these must be present to a certain excess in order to leave enough fine coal particles at the end to act as a sponge and stop any slag from attacking the retorts.

In my work on electric smelting where only 12 per cent. of coal was added, it was shown that it was possible, operating on a fairly large scale —1 ton of charge per day—to reduce zinc ore successfully with only the theoretical amount of coal. This seemingly incongruous fact points the way for certain improvements in the ordinary reduction of zinc ore in the retort. Accordingly, the above analysis of the requisites was made and investigation and research were started to find the metallurgical ultimate.

Coal-dust firing, used successfully in the cement and smelting industry, was taken as a pattern. In this, the almost instantaneous oxidation of carbon is attained by the use of coal in the form of dust. Since any reduction process is likewise an oxidation process, it is not fanciful to regard zinc reduction as an oxidation of the "charge" coal. Accordingly, tests were made, grinding both the zinc ore and the coal to 80-mesh and finer. These fine mixes were worked off in a crucible or in a retort, and while they brought out certain advantages, they also showed conclusively that the fine charge had the disadvantage of being so dense as to hold back the zinc vapor and gases and so to diminish the speed of reaction. In the conventional furnace, large pieces of coke are put in to "ventilate the charge." Accordingly, an addition was made of broom straw. These give a carbonized skeleton that is preserved during the retorting operation and provide a path for the gases so that they have a way of exit. Moreover, these carbonized skeletons or eductors are an ashless and very

active form of carbon, and thereby reduce the carbon dioxide to carbon monoxide. Since the flow of the gases naturally takes to these eductors, this super-reduction is efficient in improving condensation.

In these tests, we gradually decreased the percentage of reducing material from 60 per cent. to 50, 40, 30, 25, and 20 per cent. successively and we found that with complete reduction (residues analyzing from 2 to 0.5 per cent. Zn) there was no slagging of the ore, provided the proportion of coal was left above 20 per cent., unless the ore was especially slaggy. For instance, using an ore analyzing Zn 22 per cent., Fe 33, S 3.8, SiO_2 6.4, CaO and alkali 4 per cent., with 20 per cent. anthracite, there was slight fritting, but none with 25 per cent. of coal. In general, with reducing coal analyzing fixed carbon 67.0 per cent., volatile matter 26.6, ash 12.4 per cent. and an ore analyzing Zn 43.5 per cent., Fe 7.10, CaO 4.0 per cent. or even more, there is no trouble in getting residues that contain absolutely no "gum" or slag and analyzing in zinc as follows: 2.1 per cent., 0.6, 2.9, 2.1, 1.8, 0.5 per cent. The ore charge per retort was thus raised to 100 lb. and the coal percentage reduced to 30 per cent. or lower. The reason for this is that the charge is highly reductive, due to its fineness, and the peculiar way it is "ventilated," and since the immense number of fine particles of carbon left at the end hold up the slag-making particles and any iron sulphides, little gum is formed, and if formed it does not touch the retort walls. Instead of the carbon particles passing through the process without oxidation, many of them 3/8 in. in diameter, and without performing any useful purpose, the surface of the particles is increased 40- or 50-fold. If we hold to our original simile of coal-dust firing and if we remember that in zinc reduction two solid reagents must be made to combine, we cannot but admit the great theoretical advantage of a finely-ground porous charge.

For practical working, however, a charge must be a fair conductor of heat, for zinc reduction is heat-absorbing. This fineness of the charge, while it certainly promotes the reduction if properly "ventilated," makes the charge a poor conductor of heat, which is a decided disadvantage in the practical retorting operation.

This poor conductivity is overcome by briquetting, which causes a certain lessening of the volume, but at an expense of $1.50 per ton of ore. But since the density of coal is less than half that of the ore, the reduction of the percentage of coal from 60 to 30 per cent. or less increases the pounds of zinc ore per cubic foot from 42 to 63 lb., or increases the charge per retort from 67 to 100 lb.

Assuming a cost of $17 per ton of ore for smelting under present conditions, fine grinding, ventilating, and briquetting permits a reduction in cost, by means of increased charging, of $5.67. The reduction in "charge" coal cuts the cost of coal from $2 to $1.20. There would be a certain reduction in furnace labor and a certain reduction in retort

consumption because the charge gives a residue that blows out clean. We believe that the recovery will be increased because of low residues and decreased retort-consumption; perhaps this saving will amount to \$3. The credits thus total \$10.97 while the debit is \$1.50; or a total net saving of \$9.47 is possible.

The briquetting needs a special binder and, after mixing, can be effected by extruding through a pug mill, followed by warming or heating, leaving a partially reduced mass in various sizes suitable for charging in the conventional manner. The size of these kernels should be about ½ in. diameter.

Concluding, it may be stated that the present method of using a 400 per cent. excess of reducing coal is unscientific for the reason that such an overwhelming excess is not needed. Whether the reduction be done by solid carbon or by carbon monoxide, coal that passes through the process to a large extent in large particles, not acted on at all, serves no useful purpose except to make the charge heat-conductive. Fine grinding of coal and ore (unless it be flotation concentrates) utilizes to the maximum efficiency the coal and produces certain collateral advantages. The "kernel" briquetting gives the necessary heat conductivity. The commercialization of this proposal would, in my judgment, effect an important national saving in coal, zinc, and labor.

DISCUSSION

W. McA. Johnson.—My idea is simply that an unnecessarily large excess of coal is ordinarily used as the reducing material in a zinc charge. By fine-grinding you increase the surface, and by adding some agent like sawdust or small pieces of wood, or cotton stalks, the charge is made porous. However, the fineness of the ore and of the coal makes the charge a very poor conductor of heat, and therefore it has to be briquetted.

R. H. Eagles, Palmerton, Pa.—I would like to ask Mr. Johnson what percentage of the binder he requires, and its cost per ton of briquettes.

Mr. Johnson.—We used 10 or 12 per cent. of binder. Of course, the cost would vary according to location. The material is what is known as ordinary kerosene acid sludge, obtained from the refining of a paraffin-base oil.

O. C. Ralston, Niagara Falls, N. Y.—The present large tonnage of flotation concentrate handled by the zinc smelters is often a considerable embarrassment to them. Nearly all of them complain of the great amount of flue-dust formed during the roasting of this material. This would suggest that it is necessary to briquette, or otherwise agglomerate flotation concentrate before it is placed in the roasting furnace, although Mr. Johnson's particular proposal merely involves briquetting after

roasting, and before charging into the retorts. In fact, his proposal seems to be aimed mainly at the saving of fuel rather than better mechanical method to handle certain materials which the zinc smelter is now called upon to treat. It seems to me that the flotation concentrate problem is going to force some type of preparation of the material, like that suggested by Mr. Johnson, and it is not impossible that the necessity of briquetting the raw material will allow us to revive the old idea of mixing raw zinc sulphide with lime and a reducing agent to be charged directly into the retorts without any roasting. This, of course, would make a calcium sulphide residue, while the zinc would be distilled and condensed in the ordinary retorts and condensers.

I would like to ask Mr. Johnson just how sludge acid works as a binder? It seems possible that some zinc sulphate might be formed from the acid in the sludge, which might then decompose into zinc oxide.

Mr. Johnson.—I have not theorized on that point. We simply made some experiments with it and it seemed to work very well.

C. A. H. de Saulles, New York, N. Y. (written discussion*).—The reason for the excess coal used in the retort process, in most cases, is that it is impossible to work off a heavier charge; that is, a spelter furnace is able to reduce only a certain amount of zinc contents in a charge, no matter what form the charge is in. When using low-grade zinc ore and concentrates we have often diminished the reduction fuel to 40 per cent. of the weight of ore treated, and in some cases, where a very low-grade ore has been treated, the reduction fuel has been diminished to 30 per cent.

Mr. Johnson is certainly correct in stating that the porosity of a charge for a retort process must be considered, and it has been considered for many years. The charge should be such that the zinc vapor and gases will pass up freely into the channel above the charge, and thence into the condenser. The channel above the charge is first made by running an iron rod through the top of the charge, but this channel is soon increased in size by the settling of the charge. The art of briquetting the charge for the retort process was old when the writer went into the zinc business, 20 years ago; but so far as he knows, no substantial commercial advantages have resulted from the use of briquettes.

Woolsey McA. Johnson (written discussion†).—Referring to Mr. de Saulles' comments on this subject, the points that he elucidates bear directly on the question and are valuable as throwing light on certain difficulties and on certain misconceptions. Naturally, in any proposal it is no less important to know what not to do than what to do. The fact that briquetting in the zinc industry has been tried and has failed in the past is not proof positive of its failure in the future.

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* Received Feb. 25, 1918. † Received Mar. 1, 1918.

In the first place, briquetting for the retort plant must be "kernel briquetting" so that the briquetted mix can be charged into the retort with the scoop shovel, without modification of the present method. The fact that, with heavy charging, it is hard to work off a charge in one shift is due at present to the poor heat-conductivity of the charge and to the use of very small condensers. It would not be hard to increase the size of the condensers to catch the greater flow of zinc vapor that the finely ground, briquetted, heat-conductive charge would give. Mr. de Saulles' idea that, with rich zinc ores, coal is charged to occupy space so that the retorts can be worked off, does not seem entirely sound, for the reason that sand is cheaper, and would be used if it could; the conventional use of zinc silicate ores as a dilutent of the charge does actually produce a result resembling, but not the same as, the one he describes. Every zinc plant does charge all the ore possible with as little coal as possible, so that the maximum net effect is an optimum, blending the ore and coal for that purpose.

In every zinc charge a certain proportion of the coal is very fine, and it is those very fines, mainly, that are consumed and oxidized by the zinc ore, as is well known in the zinc industry. On the other hand, the large pieces of coal, from 1/20 to 3/8 in. are only superficially oxidized and, as I have stated, pass through the process, serving only the purpose of making the charge conductive, reductive, and porous, which I believe can be attained by my method in a cheaper and more effective manner. Since the zinc industry is having hard times, any new project should receive attention, and clear and reflective criticism such as Mr. de Saulles has given cannot fail to be of value, even when of a negative character.

High-temperature Resistance Furnaces with Ductile Molybdenum or Tungsten Resistors

W E. RUDER, SCHENECTADY, N. Y.

(New York Meeting, February, 1918)

CONSIDERABLE interest has been shown lately in various types of furnaces for the production of high temperatures, both for laboratory purposes and for small industrial uses. Dr. J. A. Harker[1] described certain modifications of the Arsem graphite resistance helix for high-temperature work at the National Physical Laboratory. Dr. Northrup also has developed two interesting forms of high-temperature furnaces.

In 1911, Messrs. Winne and Dantsizen[2] described two forms of resistance furnaces using ductile molybdenum or tungsten as resistors. Since the discovery, by this laboratory, of methods for producing these metals in ductile form, their use as resistance elements in the research laboratory of the General Electric Co. has grown to such an extent that they are now almost indispensable. These furnaces are used here for alloy research, annealing, heat-treating, and practically all of the thermal processes requiring temperatures above 900° C. Various types of furnaces have been developed to meet the general needs of laboratory work, and it is the purpose of this paper briefly to describe some of these furnaces.

A tubular furnace wound with a metallic resistor is the simplest type to construct, and almost every laboratory has made such furnaces. The only essential difference between a furnace wound with platinum or base metal and one wound with tungsten or molybdenum is that the coils of the latter must be heated in a neutral or reducing atmosphere. It has long been our custom here to build our resistance furnaces with a metallic casing from which the tube could be easily removed for rewinding. The heat-insulating material—usually calcined magnesia, alumina, silica, or silex, depending upon the nature of the resistor—is used in powdered form so that it can be readily removed and replaced. In order to adapt this method to tungsten or molybdenum windings, it

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[1] Recent Forms of Carbon Tube Furnaces. *Transactions of the Faraday Society* (1917), **12**, 3–7.

[2] R. Winne and C. Dantsizen. *Transactions, American Electrochemical Society* (1911), **20**, 287.

was necessary to make the casing gas tight and provide it with an inlet and outlet for the neutral or reducing gas.

On account of its greater pliability in heavy sections, molybdenum is commonly used for the windings. Its melting point (about 2550° C.) allows for a sufficient range above the softening temperatures of available refractories to make it unnecessary to employ the higher-melting tungsten. This holds true when resistors are run at atmospheric pressures; if, however, it is desired to run at reduced pressure or in a vacuum, tungsten is used because the high vapor pressure of molybdenum renders it unsuitable, and because a much higher temperature is available.

The resistance of tungsten at 25° C. is 5.0 microhms per centimeter cube and its temperature coefficient of resistance is 0.0051 (0–170° C.). Molybdenum has a resistance of 4.3 microhms per centimeter cube at

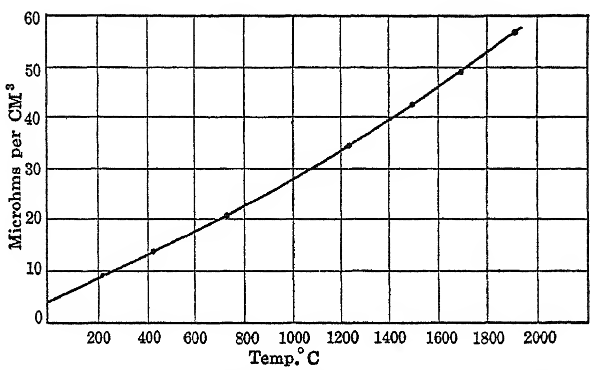


Fig. 1.—Temperature-resistance curve for molybdenum.

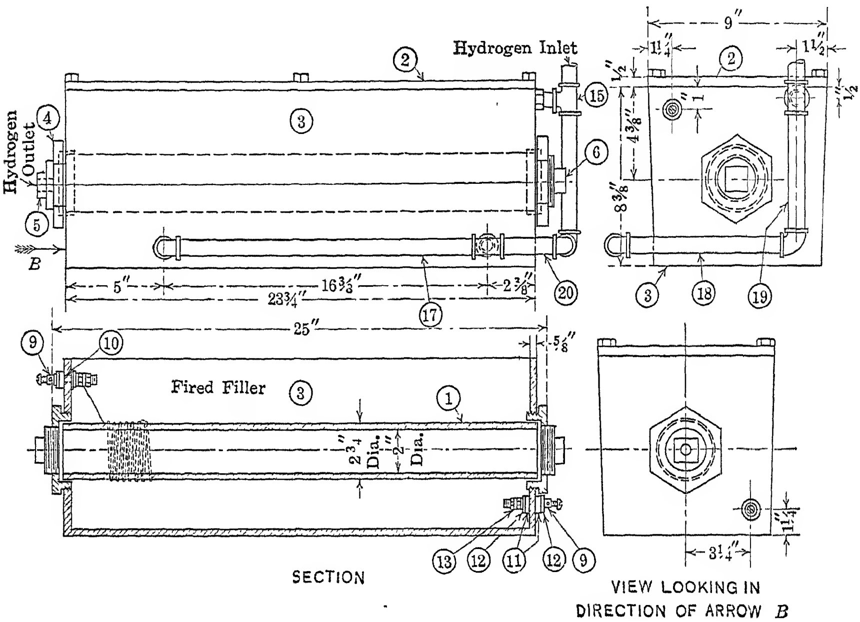
25° C. with a temperature coefficient of 0.0050 (0–170° C.). Fig. 1 shows the change of resistance of molybdenum with temperature; the curve for tungsten is so nearly the same that, for furnace purposes, the same rate of increase may be assumed.

Horizontal Tubular Furnaces

The horizontal type of furnace in greatest use is shown in Fig. 2. The alundum tube 1 is fitted into the cast-iron box 3 provided with a lid 2 which is bolted on over an asbestos gasket. The flanges 4 are screwed in to make good contact with the ends of the tube 1. Hydrogen is piped into the case through 15–20 and escapes through the alundum tube and out at 5. Nos. 9–13 show details of the current terminals.

With this furnace, temperatures up to 1750° C. are readily obtained, but if a higher temperature is attempted the alundum tube begins to sag badly. Furnaces have been successfully maintained at higher temperatures, but only with tubes of small diameter for the same thickness of wall.

Table 1 gives readings from a run on one of these molybdenum-wound furnaces. A temperature of 1700° C. may be attained in about 2 hr., but, for safety, about 3 hr. is usually allowed.



WINDINGS

Temp., C.	Length of Furnace, In.	Turns per In.	Diam. Wire, In.	Volts	Length of Wire, Ft.
-1200°	18	3	0.025	125–250	42
1200–1750°	20	4	0.034	125–250	61

FIG. 2.—HORIZONTAL TUBULAR FURNACE.

TABLE 1

Amperes	Volts	Watts	Ohms	Temp C.
9.10	44	400	4.84	550
11.10	82	911	7.39	850
11.70	92	1,085	7.95	960
12 00	101	1,212	8.42	996
12.10	113	1,370	9.34	1,100
12 70	130	1,690	10.22	1,215
12.40	133	1,650	10.50	1,300
13.20	150	1,980	11.35	1,380
14.25	175	2,500	12.25	1,515

It is often necessary to construct furnaces of larger size; these have been equally successful, but not for such extreme temperatures. A typical run on one of the larger molybdenum-wound furnaces (horizontal) is shown in Table 2.

TABLE 2

Tube.—Alundum, 36 in. (91.8 cm.) long; 3 in. (7.6 cm.) inside diameter; 3¾ in. (9.5 cm.) outside diameter.

Winding.—Molybdenum wire, 128 turns; 0.050 in. diam.; 4 turns per inch; total length, 130 ft.

Insulation.—Alumina, 4 in. thick. (Casing 12 by 12 by 37 in.)

Volts	Amperes	Watts	Ohms	Temp. C.	Time
15	6.5	97.6	2.30	.....	9.05 a. m.
104	30 0	3,120.0	3.47	.....	9.20 a. m.
256	23.0	5,900.0	11.20	red	10.15 a. m.
254	19.0	4,820.0	13.40	red	11.30 a. m.
350	24.0	8,400 0	14.60	.....	12.25 p. m.
340	22.0	7,500.0	15.40	1,430	12.40 p. m.
340	21.0	7,150.0	16 20	1,600	12.55 p. m.
340	20.5	6,970.0	16 60	1,650	1.10 p. m.
270	16 0	4,330.0	16 90	1,760	1.15 p. m.
255	16.0	4,080.0	15 90	1,760	2.15 p. m.
316	19.0	6,000.0	16.65	1,650	2.30 p. m.
308	18.5	5,700.0	16 65	1,700	3.10 p. m.
310	18.5	5,740.0	16.75	1,750	3.30 p. m.
320	18.5	5,920 0	17.30	1,760	5.30 p. m.

For maintaining a temperature of 1750–1760° C., this furnace required a total of 5920 watts or 5920 ÷ 301.6 = 19.6 watts per square inch of inside heating surface.

This particular furnace broke down after the fifth run (1750° C. for 4 hr.). Horizontal furnaces of this diameter do not last very long at this high temperature, failure being due to the sagging of the alundum tube; if the temperature is kept below 1600° C., however, a long life is possible. In fact, we have never had a burnout due to direct failure of the winding; collapse of the tube, long interruption of the hydrogen, and too rapid heating are the only causes of failure.

Another of the more useful forms of furnace used in this laboratory is the vertical type of crucible furnace. This type has been built in many different sizes depending upon the particular use to which it was to be put. The heating tube varies from 1¾ in. (4.4 cm.) inside diameter to 6 in. (15.2 cm.) inside diameter.

VERTICAL TUBULAR FURNACE

Fig. 3 shows typical construction. The figures given in Table 3 were taken from one of the runs on this furnace, which has been used for making iron alloys.

TABLE 3

Tube.—Alundum, 12½ in. (31.7 cm.) long; 3 in. (7.6 cm.) inside diameter; 3¾ in. (9.5 cm.) outside diameter.

Winding.—Molybdenum wire, 26 turns; 0.067 in. diam.; 3 turns per inch; total length, 25 ft. 10 in.

Insulation.—Alumina, 3¼ in. thick.

Current	Voltage	Watts	Ohms	Temp. C.
28.60	29.0	830	1 015	830
31.00	35.5	1,100	1.145	945
29 60	41 0	1,212	1.383	1,140
32.70	30.5	1,650	1.542	1,280
32.25	54.5	1,760	1.690	1,420
34.50	64.5	2,225	1.870	1,540
37.00	71.0	2,620	1.920	1,565

Total heating area 84 sq. in.; 31.2 watts per square inch at 1565° C.

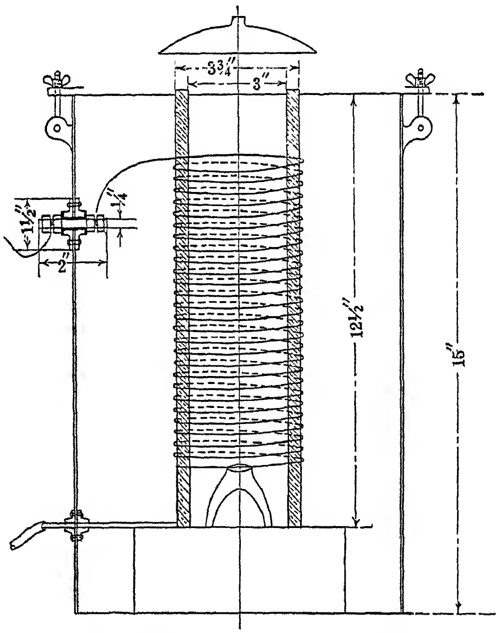


FIG. 3.—VERTICAL TUBULAR FURNACE.

The values here tabulated are also shown in the curve (Fig. 4). To maintain a temperature of 1565° C. required 2620 ÷ 84 = 31.2 watts per square inch of heating surface.

A molybdenum resistance wire, after having run at a high temperature for some time, crystallizes so that it loses much of its original ductility and can seldom be unwound without breaking. If it is not too much

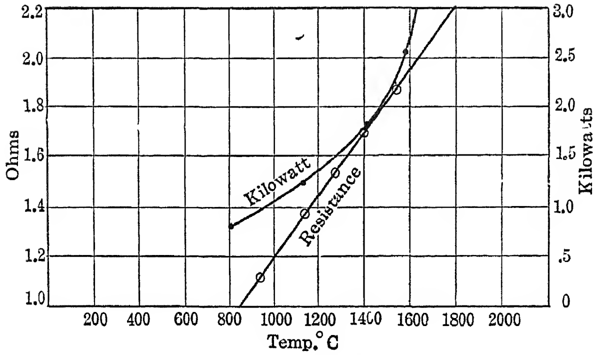


FIG. 4.—RESISTANCE-TEMPERATURE AND POWER-TEMPERATURE CURVES OF VERTICAL MOLYBDENUM-WOUND FURNACE.

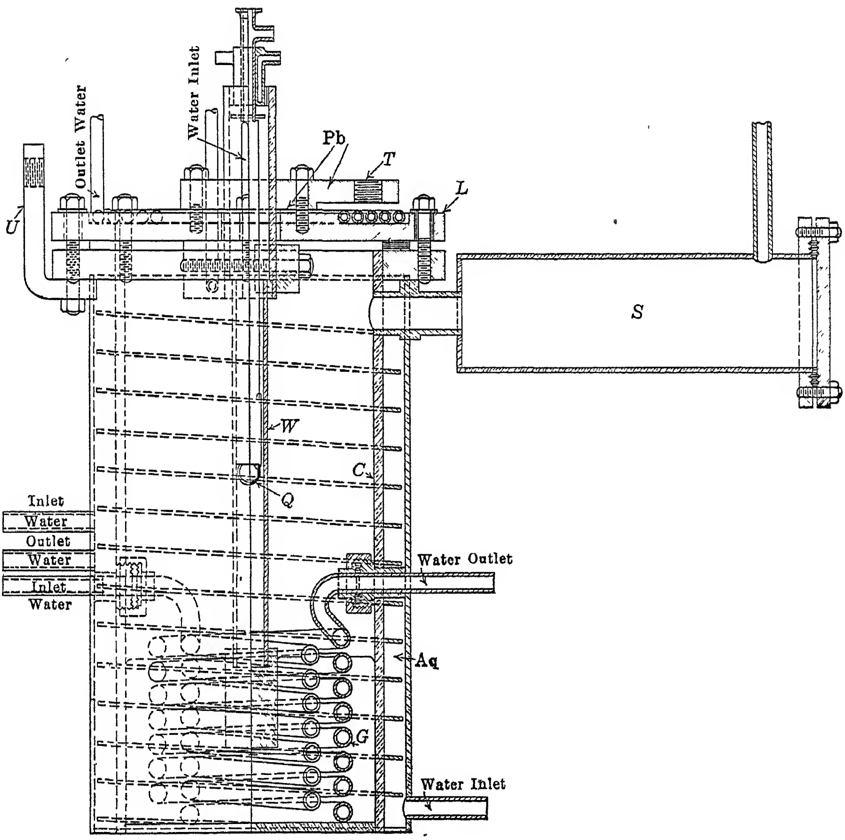


FIG. 5.—VACUUM TUNGSTEN FURNACE.

caked up with the fused alumina packing, it can be loosened and the whole winding slipped off and put onto another tube. We have in this way been able to use the same winding on several tubes.

Vacuum Tungsten Furnace

The vacuum type of furnace, with tungsten resistor, requires a different construction altogether. Fig. 5 shows a section of such a furnace. It is water-cooled by *Aq* and *Q*. *C* is the casing proper, made from a piece of heavy copper tubing. The resistor *W* is a tungsten tube suspended from the cover *L* and connected to one terminal of the transformer by the lug *T*. The lower end of the resistor dips into a mercury pool, water-cooled by the coils *G*, and the return circuit to the transformer is made through the casing and the lug *U*. The chamber *S* is of iron, in which a boat of drying agent, such as P_2O_5, is placed.

Details of the construction of this furnace and its operation will be published in a later paper by Dr. Coolidge and Mr. Hotaling, the designers.

Table 4 shows the power required to maintain different temperatures.

Table 4

Current	K-W.	Temp C.
1.46 × 1,200	3.24	1,437
1.50 × 1,200	3 60	1,502
1.74 × 1,200	4.80	1,602
2.00 × 1,200	6.84	1,802
2.50 × 1,200	13.08	2,017
3 00 × 1,200	21.92	2,237
3 20 × 1,200	26.40	2,252
3 30 × 1,200	28 80	2,307
3.40 × 1,200	30 60	2,337
3.50 × 1,200	33.36	2,447
3 60 × 1,200	36.60	2,552

This type of furnace has a decided advantage over the wire resistor type for very high temperature work, as the limit of temperature is not dependent upon any refractory, but solely upon the melting point of the resistor (3350° C.), provided oxidation is effectively prevented. In such a furnace, a temperature of 2000° C. may easily be attained in 15 min., and even more quickly if the vacuum pumps have sufficient capacity to carry off the gases rapidly.

DISCUSSION

A. E. Hall, Palmerton, Pa.—I would like to ask the author if he has ever used, in his furnaces, any inner tube which would permit experimentation with various oxidizing gases, under varying conditions?

In the work on the fusibility of coal ash in the Bureau of Mines, several years ago we made use of molybdenum and tungsten furnaces, and after using a hydrogen atmosphere, for some time we found that it was necessary to use other atmospheres. Starting with various mixtures of hydrogen and water vapor, it was finally decided to use an atmosphere, roughly, of equal parts of hydrogen and water vapor. When using that atmosphere in a furnace in which the gases came in direct contact with the wire, we found that the wire did not stand up at the higher temperatures, but oxidized very decidedly. We then attempted to use an inner tube—not porcelain, of course, because it would not stand the temperature, but something of that nature—through which we could pass other reducing gases than hydrogen, but we were not successful.

W. E. Ruder.—We have used furnaces like that, but had the same difficulty in obtaining a tube that would stand extreme temperatures without leaking gas. The alundum tubes are extremely porous. If a glazed tube is used, the glaze softens and sticks to the charge. I have not found any glazed tube that was satisfactory.

H. M. Howe, Washington, D. C.—Will Mr. Ruder kindly tell us, first, what precautions should be used to prevent explosions with hydrogen; second, whether molybdenum is injured by the oxygen present in commercial nitrogen, either as sold or after purification by any ready means, such as bubbling through pyrogallic acid? The use of nitrogen in place of hydrogen has an advantage not only as regards danger of explosions but also as regards decarburizing any specimens of iron under treatment. If the small quantity of oxygen which cannot be removed readily from commercial nitrogen injures molybdenum, at about what temperature does this injury become serious?

W. E. Ruder.—In answer to Prof. Howe's question regarding the use of nitrogen instead of hydrogen in these furnaces, I can say that nitrogen can be used and is just as satisfactory as hydrogen; in fact, owing to its higher density, should be even better. There are two reasons why we do not use it, however. In the first place, it is difficult to rid the nitrogen of all of the oxygen and this must be done or the winding will burn out. The second reason is that hydrogen is cheaper and, in our laboratory, much more plentiful than nitrogen.

There is no definite temperature below which a small amount of oxygen would do no harm. The tungsten would be attacked at a rate dependent upon the amount of oxygen present.

A very satisfactory arrangement for purifying nitrogen is to absorb the oxygen in the usual copper-ammonium-carbonate by means of a

special apparatus described by Mr. Van Brunt.[1] If still greater refinement is desired, the nitrogen may then be passed over a tube of hot copper gauze.

Henry Hess, Philadelphia, Pa. (written discussion*).—Mr. Ruder complains that the ordinary alundum tube is very porous and that an attempt to cure this by glazing the tube causes a sticking of the charge to the softened glazing. The remedy would appear to be a very simple one, consisting merely in the covering of the glazing with a second alundum tube. Such a composite tube has all of the desirable quality of the ordinary alundum itself, but is rendered non-porous by the provision of an intermediate non-porous glazing.

No doubt the Alundum Company will be pleased to furnish tubes of this character, provided the demand is sufficient, and further provided that it is able, under present industrial conditions, to respond.

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[1] *Journal, American Chemical Society* (July, 1914), **36**.

* Received May 1, 1918.

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Zinc Refining

BY LELAND E. WEMPLE,* ST. LOUIS, MO.

(New York Meeting, February, 1918)

Previous to 1915, zinc refining had not become a general practice among the zinc smelters in the United States. Such refining as had been carried on was confined chiefly to remelting very high-leaded zinc, such as third-draw metal from the retort furnaces, and slab dross, and hard spelter from galvanizing pots. In this remelting operation, the lead and iron were settled out and the refined spelter obtained graded fifth class, *i.e.*, Prime Western. Owing to the presence of lead in most zinc ores, the bulk of the spelter produced by direct smelting is of this Prime Western grade. Careful selection of ores of low lead content gave purer grades of spelter, *i.e.*, Brass Special and Intermediate; and smelters which could secure ores carrying practically no lead produced high-grade spelter. Thus, in general, the grade of spelter produced by any smelter was predetermined by the purity of the ore it could obtain.

The needs of the warring nations of Europe for enormous quantities of cartridge and other high-grade brass resulted in such a demand for the purer grades of spelter that the available supply of lead-free and low-lead ores could not produce the quantity required. Prime Western grades went begging, so to speak, while high grades sold at times from 5 to 15 c. per pound over the Prime Western market. The great demand, coupled with the wide market margin, which permitted the inherent costs and losses, resulted in the conversion of the lower grades into higher grades by processes of refining. These conditions also accentuated the development and size of the electrolytic plants, which were being worked out at the time this increased demand for pure grade of metal occurred. The electrolytic process, where available, produces a higher grade of spelter from impure ores than does the fire process; a large portion of those impurities in the ore, which by the distillation process would be carried into the spelter, are removed in the leaching of the ores and the purification of the solutions.

The refining process, adopted at a number of smelters for the purpose of converting low-grade spelter into grades suitable for brass, was that of redistillation.

* Metallurgist, American Zinc, Lead and Smelting Co.

Impurities in Spelter

The common impurities in spelter are lead, iron, and cadmium; arsenic, antimony, copper, tin, aluminum, etc., very rarely occur. All these impurities are derived from the ores. Of the common impurities, iron is the most generally objectionable for brass; especially for brass which is to be drawn or spun Lead also must be practically absent, though for brasses that must be machined, a certain amount of lead is necessary to make the cutting clean. For most other purposes, the lead is desired to be as low as feasible. Cadmium up to the extent it occurs in spelter is for most uses of spelter negligible. The processes for refining spelter deal essentially with the removal of iron and lead.

The extent to which these impurities determine the grade of spelter is shown by the following specifications proposed by the American Society for Testing Materials and adopted generally throughout the trade. The Standard Specifications for Virgin Spelter adopted by the Society, Aug. 21, 1911, are:

Grade	Assay Limits				Total
	Pb	Fe	Cd	Al	
A. High........	0.07	0 03	0 05	None	0 10
B. Intermediate..	0 20	0 03	0.50	None	0 50
C. Brass Special....	0.75	0 04	0.75	None	1 20
D. Prime Western............	1.50	0.08			

At the June, 1917, meeting of the Society, the following revision in Specifications for Virgin Spelter was recommended as tentative for consideration, upon which final vote may be taken June, 1918:

Grade	Assay Limits				Total
	Pb	Fe	Cd	Al	
1. High...............	0.07	0.03	0 07	None	0.10
2. Intermediate.................	0.20	0.03	0.50	None	0.50
3. Brass Special.......... ..	0.60	0.03	0 50	None	1 00
4. Selected........	0.80	0.04	0 75	None	1.25
5. Prime Western.	1.60	0 08			

Except the deposits of the New Jersey Zinc Co. at Franklin, N. J., and those of the American Zinc, Lead and Smelting Co. at Mascot, Tenn., and a few other smaller deposits, all zinc concentrates contain from a few tenths per cent. up to 10 per cent. or more lead. The lead content of spelter

produced by direct distillation, when treating ores carrying under 1 per cent. lead, is somewhat proportional to the amount of lead in the ores; for example, in order to produce Brass Special spelter, the lead content of the ore is kept under 0.80 per cent.; ores carrying over 1.0 per cent. lead produce approximately the same grade of spelter, *i.e.*, Prime Western. Even when ores contain no more than traces of lead, the readiness with which lead comes over results in spelter containing 0.02 to 0.05 per cent. In consequence, lead-free and low-lead ores command a premium.

Although iron occurs in nearly all zinc concentrates from 1 to 2 per cent. up to 10 or 12 per cent., the percentage carried by the zinc is not proportional to the amount in the ore. The penalty on high-iron ores is due to other reasons.

Cadmium occurs quite extensively in zinc ores, but in small proportions only, usually from 0.20 to 0.30 per cent.; the spelter carries somewhat varying proportions of cadmium. Only first-draw zinc carries a trifle higher proportion of cadmium than the ore, due to the high volatility of the cadmium.

In the distillation process, the effect of temperature and rate of distillation are also important factors which determine the purity of the spelter. The variation in temperature of the retorts from the first to last section and from bottom to top row of the furnace and during the entire distillation period is attended by a variation in the composition of the spelter. The result is very small lots, 300 to 400 lb. of uniform metal; practically every ladleful of metal drawn differs from the succeeding one.

The following table shows the common method of lotting spelter from distilling furnaces, and the assays show the variation in composition of zinc from the same furnace and the same ore:

Draw	Furnace Section	Pb, Per Cent.	Fe, Per Cent.	Cd, Per Cent
First	Ore	0.58	0.019	0.460
	Blue powder	0.82	0.039	0.330
Second	Ore	1.05	0.038	0.138
	Blue powder	1.48	0.063	0.074
Third	Ore and blue powder	1.84	0.121	0.030

It will be noted that the first-draw metal is lower in lead and iron but higher in cadmium than the other draw metal and that the blue powder metal is higher in lead and iron and lower in cadmium than ore metal. By making a preliminary draw previous to the ordinary first draw, a small amount of metal rich in cadmium, 1 to 2.50 per cent. may be obtained; while the ordinary first draw following will be poorer in cadmium it will be higher in lead, as shown by the following:

Draw	Furnace Section	Pb, Per Cent.	Fe, Per Cent.	Cd, Per Cent
Preliminary	Ore	0.46	0.022	1.5885
	Blue powder	0.50	0.024	1.4800
First	Ore	0.65	0.030	0.2580
	Blue powder	0.90	0.042	0.2070

Or, by delaying the time of making the first draw, the content of cadmium in the first-draw metal may be reduced, but also at a sacrifice of low-lead content, as for example:

	Pb, Per Cent.	Fe, Per Cent.	Cd, Per Cent.
Heavy first draw	0.615	0.032	0.40
Second draw	1.600	0.046	0.08

Methods of Preventing Contamination of Spelter

The methods in use for preventing contamination of spelter are at present only relatively successful, but by removing portions of the contaminating elements, they tend to raise the grade of spelter product. In concentrating zinc ores by milling and other methods, the endeavor is made to remove the lead- and iron-bearing minerals, and produce concentrates as free from these impurities as possible. Other processes remove the cadmium by a preliminary treatment of the ore before it is smelted. The electrolytic plants prevent contamination of their spelter through the selective action of certain solvents which do not dissolve the lead, and by means of precipitating agents largely remove the iron and cadmium.

In the distillation process, various means have been proposed but not extensively used, for the prevention of contamination of the condensing zinc vapors. The methods[1] proposed consist of placing dams or filters in the mouth of the retort or butt of the condenser. Filters may consist of a porous pack of suitable-sized refractory material; a porous coal, coke, or charge mass specially prepared, or the last shovel of charge put in the retort may be essentially coke. Dams may be of fire clay or coke. Both dams and filters are effective in reducing the lead and iron content of the

[1] British Patent 25,099 (1907), Evans H. Hopkins.
U. S. Patent 905,753 (Dec. 1, 1908), Edward H. Shortman.
British Patent 4563 (1909), 452 (1910), Henry E. Howard.
U. S. Patent 963,416 (July 5, 1910), Chas. S. Brand.
U. S. Patent 1,166,447 (Jan. 4, 1916), C. A. H. de Saulles.
J. S. G. Primrose: Fume Filtration for Production of Pure Spelter. *Engineering & Mining Journal* (Aug. 27, 1910), 90, 415.

zinc, but have no apparent effect on the cadmium. For example, their effect on the lead content is as follows:

Zinc	First-Draw Metal, Per Cent. Pb	Second-Draw Metal, Per Cent. Pb
Condenser without dam	0.58	1.48
Condenser with dam	0.28	0.36
Condenser without filter	0.66	1.28
Condenser with filter	0.14	0.15

Their use has likewise shown the iron content of the zinc to be reduced from 0.07 to 0.02 per cent. Dams, however, have found disfavor, as they tend to reduce the yield of spelter. Part of the zinc condenses back of them in the retort during the early period of firing, and during heavy firing later in the shift this zinc is overheated and largely escapes uncondensed through the nose of the condenser. Filters may lose their porosity through deposition of charge mix, blue powder, or metal, and unless frequently renewed act in the same manner as dams. Preventing contamination of the spelter with iron can be accomplished equally well by using a scratcher provided with a guard which permits it to enter only to the butt of the condenser. One of the chief sources of iron contamination has been found to be due to scratching a portion of the charge in the mouth of the retort into the molten zinc when drawing metal. A decrease in the lead and iron content of the spelter is also effected by briquetting the entire retort charge. Circular briquets having a diameter slightly smaller than the retort and cored at the center for charging on a rod, yield spelter containing but a few hundredths per cent. lead and a few thousandths per cent. iron. However, such briquets are not practical. It is more feasible to use smaller briquets and charge them in the usual manner, but in this case the amount of lead and iron held back is much less and if the briquets disintegrate during distillation there is practically no change in the spelter composition from that of an ordinary charge. The following assays show the effect on first-draw metal when using small briquets which did not disintegrate:

	Pb	Fe	Cd
Briquetted charge	0.792	0.014	0.260
Ordinary charge	1.09	0.021	0.254

The retention of the lead and iron by the briquetted charge is probably due to the filtering action and the higher heat conductivity of the briquette which produces a more uniform temperature throughout the

retort. It will be noted that cadmium, which is reduced and volatilized at a lower temperature than zinc, is apparently unaffected.

Refining Spelter by Redistillation

Although this method of purifying spelter has come into extensive use only during the past 3 years, it has been used in a rough way for a number of years to convert very impure and unsalable zinc, such as third-draw metal, galvanizers' slab dross, etc., into marketable spelter. Such operations, however, were conducted on a small scale, and chiefly by producers of secondary metals.[2] In 1896, G. M. Holstein and J. D. James took out a patent[3] covering the process of refining zinc and separating it from lead, consisting in redistilling the zinc from impure spelter charged into an inclined retort having the butt end about 4 in. lower than the mouth. The spelter was charged into the retorts in the form of bars. As soon as the spelter melted, the lead, owing to its greater specific gravity (lead 11.4, zinc 6.86), settled out and collected in the lower part of the retort at the butt end. The retorts were carefully maintained at the temperature at which zinc volatilizes, but below that at which lead volatilizes. The furnace for carrying on this operation consisted of a single unit; *i.e.*, the back wall, which in the case of the ore-smelting furnace is a center wall and supports the rows of retorts on each side, was an outside wall with openings opposite the butt end of the retort. These openings were for the purpose of cooling the metal in the butt end of the retort, thereby diminishing the ebullition at this point and giving a quiescent condition to the molten metal which promoted the settling out of the lead. By lowering the temperature of the metal in the butt end to below the volatilization point of lead, this chilling also prevented the lead from going over with the zinc. Besides chilling the butt of the retort by exposing it to the air, air might be introduced into the combustion chamber through a hole in the brickwork surrounding the butt of the retort and directly under the retort, or the butt end of the retort might be cooled by means of a water jacket in the furnace wall. An ordinary conical condenser was temporarily luted into the mouth of the retort for condensing and collecting the zinc distilled over. These condensers were provided with a semicircular bridge wall or dam at their large end, to prevent the boiling metal in the retorts from slopping over into the condenser and also to prevent pure molten zinc in the condensers from flowing back into the retort. The nose of the condenser was partly stuffed.

Two methods are now extensively used for carrying on the redistillation of zinc in a manner similar to the Holstein-James process. The older method makes use of an ordinary smelting furnace block; the later

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[2] R. H. Engle: The Engle Furnace for Redistilling Spelter. *Engineering & Mining Journal* (July 29, 1916), **102**, 213.

[3] U. S. Patent 554,184 (Feb. 4, 1896).

method invented by C. A. H. de Saulles[4] uses a single furnace with back wall exposed.

Converted Smelting Furnace Method

The conversion of an ordinary ore-smelting furnace into a redistilling furnace is accomplished by removing the lower row of retorts and placing the butts of the upper rows on the shelves of the next lower row, which gives the retort an inclination of about 8 to 10 in. in its length and permits it to hold a bath of molten spelter. As a lower temperature is required for redistilling than for smelting, the flue checkers are opened and the combustion gas is burnt under natural draft instead of the common plus pressure condition. This results in a thin flame, more uniform heat, better heat efficiency, and allows the firemen to see the entire retort in the furnace and detect leaks. The size of the distilling furnace, *i.e.*, number of retorts, is obviously predetermined by the size of the original ore-smelting furnace. For example, at one gas smelter the removal of the lower row of retorts reduces the number of retorts per block from 608 to 456; *i.e.*, each furnace is three rows high and has 228 retorts. Some plants use an ordinary condenser which has a semicircular dam in the large end; others use a hand-made condenser which is like a truncated cone, the smaller end (7 in. diameter—17.8 cm.) containing the dam being luted into the retort, while the large outer end (10 in. diameter—25.4 cm.) is closed with a fire-clay plate having semicircular openings at the top and bottom; during distillation these openings are stuffed up in the same manner as the nose of the ordinary condenser. Fig. 1 shows the charging of the zinc into the retort of a natural-gas-fired redistilling furnace with the large condensers. The method of drawing and casting the spelter is similar to the same operations in ordinary practice. The spelter to be refined is either remelted in a settling furnace and then cast, or cast direct from the ore furnace into sticks about 20 in. (50.8 cm.) long by 1½ in. (3.8 cm.) by 1 in. (2.54 cm.) weighing about 10 lb. (4 kg.). Four or five of these sticks make a charge for one retort, the retorts being charged immediately after each drawing. The retorts are charged without removing the condensers, by inserting the sticks through the top opening of the condenser over the dam and giving them a slight push, as shown in Fig. 1. Immediately after charging, the condenser is stuffed and in 5 to 10 min. the chilling effect of the cold sticks introduced into the retort has been overcome and distillation is resumed. The furnace is kept at a uniform heat, no increase or cooling off takes place as with ore smelting. The condensers are drawn periodically, when using the large condenser every 6 hr.; whereas, when using small condensers, their limited capacity necessitates drawing more frequently, for example, every 4 hr. In drawing the condensers the top hole is spiessed first to relieve the gas pressure

[4] U. S. Patent 1,215,007 (Feb. 6, 1917.)

within and then the scratcher is inserted in the bottom hole and the contained metal and blue powder are drawn with regulation draw bar and ladle.

The redistilled spelter in the ladle is cast into plates which are taken to the equalizing furnace for remelting and recasting into the finished plate of uniform high-grade spelter. As the bath of metal in the retort becomes enriched in lead and iron, it must be removed. This is accomplished periodically by omitting the charge for a few periods on one section (nine retorts) daily and the next day by taking down the condensers from this section and scraping out the lead bottoms with a large scraper. Two or 3 hr. are required to clean out bottoms. In case of leaky retorts the

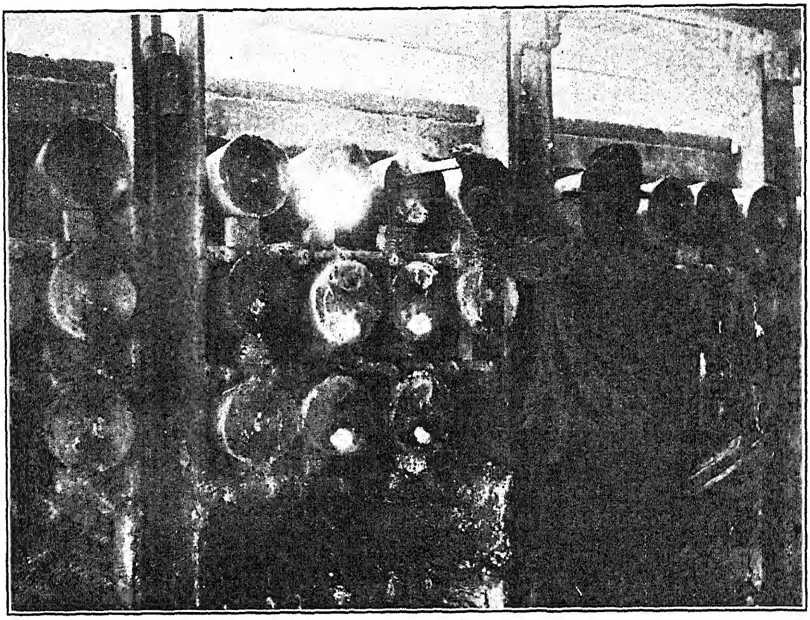

FIG. 1.—CHARGING IMPURE ZINC FOR REDISTILLATION. CONVERTED SMELTING FURNACE EQUIPPED WITH LARGE CONDENSERS.

condensers are taken down and the contents of the retorts drawn in the same manner; a new retort is put in and operations continued. The leady bottoms are drawn into a slag pot from which they are cast into plates and taken to a remelting furnace where any excess zinc is separated. The lead tapped from the remelting furnace, carrying about 1 to 2 per cent. zinc, is sold to lead refiners. The blue powder, skimmings, etc., from the redistilling, remelting, and equalizing furnaces are returned to the ore furnaces for resmelting. All scrap is returned to the remelting furnace to be recast into sticks for recharging. The crew for operating a redistilling furnace consists of the following men per 12-hr. shift: one first charger who charges the sticks and draws the lead bottoms; one sec-

ond charger who brings up sticks, stuffs condensers, stacks plates, etc.; one metal drawer who draws metal only; one helper who helps draw bottoms, change retorts, etc.; and one fireman who tends both furnaces in the block and acts as foreman of the labor.

De Saulles Method

The de Saulles process uses a specially constructed furnace equivalent to one side of an ordinary furnace block. The retorts are inclined about 7 in. (17.8 cm.) in their length and extended through the back wall 4 to 5 in. An opening is provided at the top of the protruding butt end through which the retort is charged with molten spelter; at the bottom of

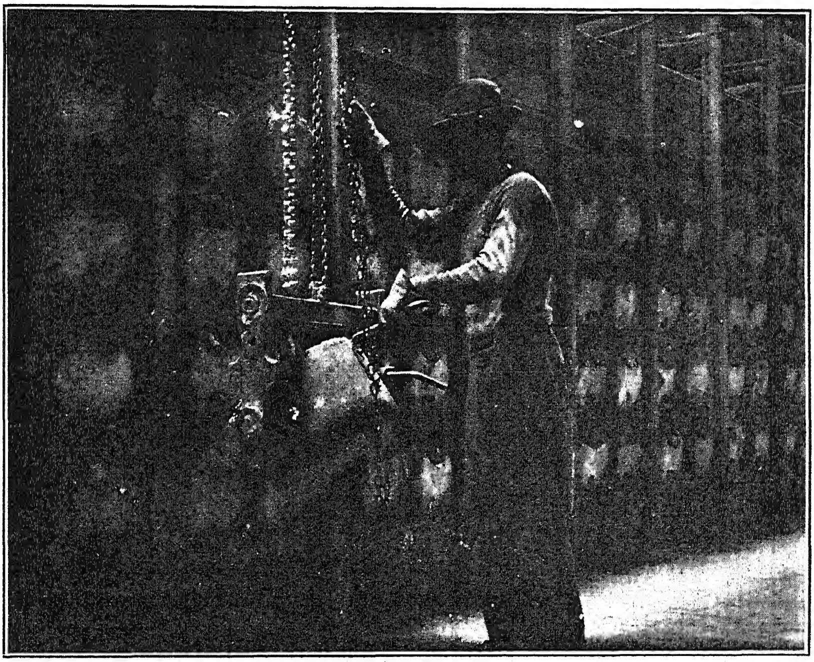

FIG. 2.—CHARGING IMPURE ZINC FOR REDISTILLATION, DE SAULLES PROCESS.

the butt end a small opening is provided through which the leady bottoms are tapped out; both openings are tightly closed with clay except when charging and tapping. The condenser used is of the ordinary shape and size and is clayed into the retort.

The furnaces are fired with natural gas or coal, Belgian style, using a thin flame and natural draft. The furnaces are two, three, and four rows high and contain from 80 to 200 retorts. Each retort-distilling furnace is served by one 25-ton remelting furnace and one 25-ton equalizing furnace; the three furnaces are built close together and comprise a redistillation unit. One equalizing furnace may be dispensed with by

operating two units together. Fig. 2 shows the method of charging the retorts. The spelter to be redistilled is melted down in the remelting furnace, where a large part of the lead settles out. After settling, the metal is drawn off from the top of the molten bath into a ladle by cutting down a clay retaining dam. The ladle, suspended from a trolley, is moved along the back wall of the retort furnace and by means of a chain block raised and lowered to the necessary height for emptying its contents into the butt end of the retort, as shown by Fig. 2. The retorts are charged in this manner once in 24 hr.; the two top rows at 7 a.m. and the two bottom rows at 7 p.m. The charge openings are closed with clay packing immediately after pouring in the metal, and distillation of the zinc is resumed with a minimum delay, as the furnace is maintained at a uniform heat throughout the 24 hr. The condensers are drawn every 4 hr. Great caution is exercised in spiessing the stuffing before drawing in order to avoid the spurt of zinc and blue powder caused by the high gas pressure frequently occurring in the condenser. The draw ladle containing the redistilled zinc is moved along an overhead trolley to the equalizing furnace where its contents are emptied. The equalizing furnace serves the purpose of cooling the overheated metal from the condensers and blends the metal from the various draws into car lots of uniform spelter. This furnace is drawn during the day shift only, the metal being drawn off into a ladle by cutting down the retaining dam at the surface of the metal. The refined spelter is transferred on an overhead trolley to the mold racks and cast into finished plates of high-grade spelter. The leady metal is tapped once in 48 hr., half of the retorts being tapped each 24 hr.; about 20 lb. are removed from each retort. Every 10 days the retorts are tapped completely dry and the leady metal obtained is returned to the remelting furnace. The tapping operation takes place about 2 hr. before charging, in order that the lead returned to the remelting furnace may have time to settle out and may not be returned with the next charge metal. Every 2 or 3 weeks the accumulation of lead settling in the bottom of the remelting furnace is tapped out through a bottom tap and cast into molds. This lead containing 1 to 2 per cent. zinc is shipped to lead refiners. All redistilled scrap is returned to the equalizer and leady scrap to the remelter. Blue powder, dross and skimmings are resmelted in the ore furnaces. The labor, per 12-hr. shift, required to operate a double unit of furnaces, consists of one metal drawer and two chargers; on the day shift an extra man is used to help change retorts, etc. One fireman tends two double units. The metal drawer does nothing but draw the condensers and pour the metal into the equalizer; one charger handles the ladle for charging and drawing leady metal; the other charger stuffs the condensers, helps the first charger and draws the equalizer. Both chargers charge the remelting furnace.

Results of Refining by Redistillation

While these two methods of redistilling spelter differ in furnace design and consequently in operation, the grade of impure metal treated, the purity of the product, percentage loss, and percentage of byproducts produced are practically the same; hence the following data pertain to both methods except when the contrary is noted.

Grade of Metal Charged

The spelter ordinarily charged to redistilling operations consists of second- and third-draw metal and contains 1.5 to 3 per cent. lead, 0.03 to 1.0 per cent. iron and 0.03 to 0.07 per cent. cadmium. In the case of the converted smelting furnace method, metal of such composition is charged direct to the redistilling pots, but in the de Saulles method the preliminary settling in the remelting furnace results in metal carrying about 1 per cent. only of lead and 0.03 to 0.05 per cent. of iron being charged into the redistilling pots.

Grade of Refined Zinc

The redistilled spelter contains from 0.03 to 0.12 per cent. lead, 0.008 to 0.012 per cent. iron and 0.03 to 0.07 per cent. cadmium, averaging 0.10 per cent. lead, 0.01 per cent. iron, 0.04 per cent. cadmium; 99.85 per cent. zinc, and is a much better grade of spelter than the ordinary Intermediate grade as specified by the American Society for Testing Materials. In producing such low-lead spelter, it is necessary to maintain at all times in the redistilling pots a large preponderance of zinc, for the amount of lead coming over depends upon its partial pressure and the effect of mechanical entrainment. The more rapidly the zinc is distilled, the more violent the ebullition, and consequently the greater the amount of lead carried over into the condenser by mechanical entrainment. This entrainment effect is frequently observed when a "hot spot" develops in the furnace, or the furnace is being driven for increased production, even though the pots have just been recharged with fresh zinc. Hence the method of controlling the lead content of the redistilled product consists in maintaining at all times a uniform heat throughout the furnace, frequently refilling the retorts with fresh zinc and frequently tapping off the leady metal concentrating in the bottoms. The retorts as inclined in the furnaces hold from 250 to 300 lb. (113 to 136 kg.) of molten metal. In the de Saulles furnace, about 175 lb. of metal, containing about 1 per cent. Pb, are charged per retort at one time in 24 hr., and the equivalent of 15 lb. per retort of leady zinc containing 3 to 6 per cent. Pb is tapped from the bottoms every 24 hr. In the converted smelting furnace method, about the same amount of metal, containing about 2 per cent. Pb, is

charged per retort per 24 hr., but in 6-hr. intervals; about 200 lb. of leady bottoms containing 10 to 15 per cent. lead is drawn every 15 or 20 days, or the equivalent of 15 lb. per retort per day. Because of the frequent replenishment of the retort with spelter, although higher in lead, the metal in the converted smelting furnace retort does not reach a higher lead concentration than that of the de Saulles process retort filled but once per day with lower leaded zinc. The higher-lead bottoms drawn from the converted smelting furnace retort are obtained by omitting charging for a day, and maintaining distillation until a high concentration of lead is effected. Careful control of the lead suffices to keep the iron content in the redistilled spelter ordinarily under 0.01 per cent. Practically no separation of the cadmium takes place; all of it comes over with the zinc.

Yield of Refined Zinc

The average yield of redistilled spelter per retort per day by both methods is about 150 lb. (68 kg.), although as much as 166 lb. (75 kg.) has been produced. The frequent charging of small amounts of cold metal in the converted smelting furnace method avoids overchilling the bath, and interrupts distillation for only a few minutes. Approximately the same conditions are obtained in the de Saulles method through having the larger quantity of charge metal in a molten condition when charged. Drawing off the lead is a much simpler operation and attended with less interruption of distillation with the de Saulles method.

Byproducts

Besides the more or less scrap, skimmings, and dross attending remelting and pouring charge and redistilled metal, there is the ever-present formation of blue powder in the condenser; and as this blue-powder product is augmented by frequently opening the condenser, a decided advantage is obtained by using a large condenser, which requires less frequent drawing. The rich, uniformly heated zinc vapor from the redistilling pot does not give the condensation troubles that occur with the lean, unevenly heated vapors from an ore charge. The proportion of metal going into the byproducts, blue powder, scrap, and skimmings, is about 15 per cent. with both processes. The distribution of metal charged to redistillation operations averages approximately:

	Per Cent.
Redistilled spelter	80
Byproducts	15
Metal loss	5
	100

The greatest source of metal loss is with the retorts. The heavy load of metal which the retorts carry at a high temperature sets up strains which only the best made retorts can withstand. Small cracks formed in drying and annealing, or in the retort furnace, rapidly open up, permitting the molten metal or zinc vapor to escape into the combustion chamber of the furnace where it is carried off through the stacks as oxide. On this account, careful and frequent inspection of the furnaces must be made for leaky retorts. Also, the more dense the walls of the retort are made, the smaller the amount of permeation by the molten metal and vapor. It has been found that retorts made in a hydraulic press under the heaviest pressure give the least loss of metal and longest life. The average life of retorts made by the Wettengel hydraulic press has been better than 60 days, as compared with 20 to 30 days of retorts made in other presses. No flame appears on the condenser under ordinary firing, and hence no loss of zinc occurs through escaping uncondensed vapors. Such loss as occurs at the condensers takes place during drawing and charging; a slight loss of zinc occurs during charging by either method.

Other Redistilling Methods

Jacob Collman and Rudolph Bowmann,[5] propose a continuous process of refining zinc by redistillation, which consists in melting the spelter, passing it in a molten conditio nand in a thin stream or layer through a suitable conduit placed under the melting pot and subjecting it to a gradually increasing heat in this conduit until distillation temperature of the zinc is reached. The zinc vapor is led off into a condenser where it is condensed into the refined spelter, the molten lead and iron are trapped out of the zinc vapors, and flow off into a separate receiving vessel. The conduit may be filled with pieces of fire-resisting inert material or coal in order to insure a perfect distribution of the zinc to be distilled.

Various other methods of carrying out the redistilling operation have been proposed; for example, extensive experiments have been made with furnaces heated electrically for the purpose of closer temperature control in order to affect separation of the cadmium as well as lead and iron. Others have tried systems of countercurrent heating and conserving the latent heat of condensation of the zinc to effect separation of the cadmium, etc., but such efforts have not so far developed a commercial process.

Refining by Remelting

Remelting or tank furnaces are used by several smelters for equalizing the composition or for refining spelter by remelting and settling out the lead and iron. Lots of spelter containing under 0.80 per cent. lead, or that will grade as Brass Special, are remelted in a remelting furnace, hold-

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[5] U. S. Patent 827,418, July 31, 1906.

ing about 30 tons of molten metal. This is a simple remelting operation which serves to equalize the composition of the small lots produced from different parts of the retort furnace and yields uniform spelter in carload lots. Lots that contain over 0.80 per cent. lead, or which grade as Prime Western spelter, are remelted in another furnace. The plates are slowly melted in the furnace and after standing 18 to 24 hr. to permit the lead and iron to settle, the top metal is drawn off and the tank replenished with more plates. In this way, a certain amount of refining can be accomplished; for example, the lead content of the top metal may be lowered to 0.90 to 1.20 per cent. and the iron to 0.030 to 0.040 per cent. As these remelting furnaces fill with lead and iron, the bottoms are tapped and the heavy metal run out, or the top zinc is drawn off and the heavy metal dipped out. The separation of the lead in these furnaces depends upon the fact that its specific gravity (11.4) is higher than that of molten zinc (6.86) and upon its decrease in solubility in zinc at the melting temperature of the latter. Iron separates in the form of an alloy (hard zinc containing 5 to 6 per cent. Fe) and collects on top of the lead. This hard zinc is removed from time to time with a perforated shovel and returned to the retort furnaces with the dross and skimmings.

Remelting furnaces are built with a deep basin for the purpose of maintaining the lead accumulation, between infrequent clean-out periods, well below the top zinc, in order that it may not be stirred up by the surface agitation during charging and drawing. The basin is frequently divided by two or three partition walls with slots near the metal level to permit only top metal to flow from one compartment to the other. A sheet-iron shell to prevent metal leaks incloses the bottom and extends around the sides to the metal level. Furnaces are fired by gas or coal, using a reducing flame, the flame being held close to the surface of the metal by means of a low arch. Plates of spelter to be remelted and refined are charged at the fire end, either in a separate compartment or on a sloping hearth, and the refined metal is drawn from the last compartment at the other end. Drawing is accomplished either by dipping with a ladle or by cutting down a dam and allowing the top metal to flow into the ladle; the metal is then cast into finished plates of uniform spelter. Control of the quality of the refined spelter consists in slowly melting the charge plates, keeping the temperature of the metal at the drawing end slightly above the freezing point, not permitting the lead and iron accumulations in the bottom to get within 10 to 12 in. of the surface of the metal and maintaining the surface of the metal at practically the same level when operating continuously; that is, in not drawing out more metal than is put in and slowly melted. The leady metal from the bottoms, carrying about 97.5 per cent. lead, 2.5 per cent. zinc, and 0.01 per cent. iron, is shipped to lead refiners. The distribution of the zinc contents in the production of 1 per cent. lead spelter is approximately:

	Per Cent.
In refined spelter	91.5
In dross and skimmings	5.5
In lead metal	1 5
In metal loss	1.5

Other Methods of Refining by Remelting

Other methods have been proposed for refining zinc in the molten condition, such as introducing other substances which would combine with the impurities and bring them to the top or carry them to the bottom. Delfo Coder[6] proposes the introduction of copper or copper aluminum alloys into molten impure zinc, and the distilling off of the zinc which the copper or alloys take up. Richards[7] removed the iron from galvanizers' slab dross, on a commercial scale, by introducing potassium cyanide and sulphur into a bath of impure zinc. The iron settled to the bottom as sulphide. He also accomplished the same result by using leather scrap and potatoes as substitute for the potassium cyanide.

DISCUSSION

E. G. Spilsbury, New York, N. Y.—I would like to ask Mr. Wemple what is the total loss in redistillation; not merely the weight of the lead removed, but also the loss due to rehandling of a large amount of blue powder, and that due to the final remelting in the tank furnace?

Leland E. Wemple.—The loss of zinc by redistillation, on the first operation, is approximately 5 per cent. This loss does not cover the lead which is separated out. Such lead should not be considered a loss, because it is finally recovered from the remelting furnaces in an impure state, containing perhaps 1 or 2 per cent. of zinc, and is sent to the lead refiners, who refine it into good merchantable pig lead.

The byproducts, consisting of blue powder, skimmings, and scrap, contain about 15 per cent. of the spelter charged. About 2 or 3 per cent. is leady scrap, which has to be returned to the remelting furnaces. About 12 per cent. is blue powder, which has to go through the reduction process. The total loss of zinc is therefore in the neighborhood of 6 or 7 per cent. of the zinc contents charged. This covers the entire operation of redistilling, remelting, and the production of the finished plate.

W. McA. Johnson, Hartford, Conn.—I would like to ask Mr. Wemple what proportion of the lead in the refined product is carried over mechanically and what proportion is carried over by the vapor pressure of lead

[6] German Patent 207,019 (1907).

[7] E. S. Sperry: Zinc Dross and Its Refining. *Brass World* (December, 1906), **2**, 409.

at a temperature, say, of 950° C., at which the redistillation process operates?

Mr. Wemple.—I do not know of any definite data as to the proportion of lead carried over by entrainment as distinct from that carried over by the vapor pressure of lead at temperatures of distilling spelter. But by running the furnace slowly, at a low heat, very close to the boiling point of zinc, it is possible to produce redistilled spelter with as little as 0.03 per cent. lead. As soon as the temperature is raised, you get a higher partial pressure from the lead, the molten zinc boils more vigorously, and the lead content increases. A hot spot in the furnace, or rapid firing for increased production, may result in as high as 0.25 or 0.30 per cent. lead in the redistilled zinc. If you are not careful to maintain a large preponderance of zinc in the retorts, the lead content of the distilled product goes right up. The care with which the heat is controlled is the main point in redistilling for a low-lead product.

Mr. Johnson.—While spelter remains fairly high in the retort, the temperature cannot rise very high, because the latent heat of vaporization of zinc is about 400 calories per kilogram.

Mr. Wemple.—The retort can be heated so rapidly as to superheat the zinc vapor until it will not condense in the stuffed condenser; the percentage of lead will then increase greatly.

W. McA. Johnson (written discussion*).—Mr. Wemple's paper covers comprehensively a subject which has come into industrial prominence as a result of war conditions, and it seems that in the future certain circumstances must arise that will make his subject one of lasting metallurgical importance. Ordinary "Prime Western" spelter is non-uniform as to individual slabs and often carries, besides the impurities chemically combined—as lead and iron—such impurities as fine carbon, zinc oxide, and zinc sulphide. This non-uniformity of the individual slabs is undesirable, because, while a carload may analyze satisfactorily, certain slabs may be "off." When one of these slabs is then put in the crucible at the brass foundry, serious irregularity may ensue, while, on the contrary, a purer slab may cause irregularity by reason of its very purity. The presence of the physically combined impurites also causes loss both in the brass works and in the galvanizing plant, for they are potent factors in making dross.

It seems natural to expect that the retort plant, facing the competition of the electrolytic plants, must hereafter more generally adopt the plan of pouring all its metal into one or more mixers or "equalizing" furnaces,

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* Received Feb. 27, 1918.

from which the slabs are cast, thereby making the slabs uniform, of a guaranteed analysis, and entirely free from dross. This would settle out the lead and iron and make a spelter 99 per cent. pure.

Moreover, there is going to be an increasing demand from the brass and other alloy manufacturers for high-grade spelter analyzing 99.90 per cent., and for intermediate grades. The retort can supply this either from low-grade ores, by redistilling, or from specially selected ores low in lead and iron. Brass-special grade can be made by mixing high-grade and settled spelter.

The distillation of metal, as distinguished from the reduction and simultaneous distillation from oxidized zinc ores, operates at a low temperature, 920° C., slightly above the boiling point of zinc. While there is any zinc left in the retort, the metal keeps closely to its boiling point and carries over with it such proportion of lead as the vapor tension of lead at the temperature calls for. Mathematically expressed, we have: $P \times 100 = VPb \div 760$, where P is the percentage and VPb the vapor pressure of lead.

In Richard's "Metallurgical Calculations," Vol. III, page 558, we find:

Tension of Lead Vapor, in Mm. of Hg.	Temp., °C.
0.004	735
0 045	844
0.280	954
1.470	1,064
5 730	1,173
18 250	1,283

Interpolating, we have these values:

Temp , °C	Vapor Pressure of Lead	Theoretical Lead in Spelter, Per Cent.
900	0.10	0.013
925	0 17	0 022
950	0.25	0.033
975	0.39	0.051
1,000	0.59	0.078
1,025	0.86	0.113
1,050	1.18	0.159
1,075	1.69	0.222
1,100	2.20	0.290
1,125	3.00	0.396
1,150	4.20	0.554
1,283	18.25	2.400

The figures in the third column are obtained by calculation, using the above equation.

Provided the redistillation retorts are full of zinc, the temperature cannot rise much above 950° and it is possible to hold the grade of spelter to 0.05 per cent. lead. However, if the retort spits over fast, lead is carried over, since, as the metal is lowered in the retort by the process, the temperature quickly rises because the cooling effect of the evaporation of zinc no longer operates. Practical experience also teaches that the retorts must be kept clear of the leady residue, and often refilled with zinc. If this is done, metal of very high grade can be made. For the reduction of ore, these calculated figures must be multiplied by two or more, since the partial pressure of the CO, and other gases, reduces the partial pressure of zinc.

It may be remarked that the small eastern reclaiming plants, using high-necked, large graphite retorts, operating on dross, often make surprisingly high-grade spelter out of very poor material.

Bone-ash Cupels*

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(New York Meeting, February, 1918)

BONE-ASH cupels have been used from time immemorial to absorb litharge, and accompanying oxides, in assaying. Doubtless, also, from the earliest days cupels have been most unjustly blamed for much poor assaying. It has long been known that the precious metals go with the litharge into the cupel. This occasions a loss of precious metals and reduces the results of the assay. There have been many investigations of cupels and the most diverse views have been expressed, the extremes being the statements of Lodge[1] that every cupel has some effect upon the loss in assaying telluride ores and of the Campredons[2] that coarse and fine and hard and soft cupels all give the same loss of silver when cupelling the same weights. The truth lies between these statements and much nearer the latter. In a vast majority of cases the influence of the cupel is not dominant and is outweighed by other conditions, particularly the temperature of the cupelling bead.

At the Spokane meeting of the Institute I presented a paper on the Assay and Valuation of Gold Bullion,[3] which recorded the results of many hundreds of assays made in the Mint service under everyday commercial conditions, which of necessity differ from scientific conditions.

In following this matter up, for the purpose of increasing the accuracy of our commercial methods of bullion assays, the question of the absorption of gold by the cupel was found to be a most important one and was taken up for investigation. In a lesser degree, the silver absorption is important and interesting, but at present it appears to be far more complicated and, while many figures showing silver absorption may be found through this paper, much further investigation is required to put the subject upon a satisfactory basis.

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† Assayer, Bureau of the Mint.

[1] R. W. Lodge: Assaying Telluride Ores for Gold. *Technology Quarterly* (1899), **12,** 171.

[2] G. Campredon: Importance des différentes causes de pertes d'argent à la coupellation. *Revue Universelle des Mines,* Ser. 4 (1904), **8,** 210.

[3] *Trans.* (1909), **40,** 780–797; *Annual Report of the U. S. Director of the Mint* (1909), 25.

In order to get a preliminary view of the question of gold absorption in cupelling gold bullion, certain samples of very pure gold, which were being sent out to various laboratories in the Mint service for comparative assaying, were assayed in sets of six with three proofs. The nine cupels were arranged in the muffle in a square, the three proofs occupying the middle line from front to back. On completion of the assays, the used cupels were properly marked to show their position in the muffle and forwarded to the Bureau laboratory accompanied by a report giving the assay results obtained in each cupel, including the proof figures.

In the Bureau laboratory, the used portion of each cupel was carefully separated from the unused portion and ground to pass 100-mesh. The powder was weighed and mixed with an equal weight of litharge and of bicarbonate of soda and 0.5 gram of flour. Owing to the refractory nature of the phosphate of lime, a small amount of cryolite was added to liquefy the fusion. The proportion of bone ash saturated by the litharge varied somewhat in the different laboratories, but in general cryolite one-eighth to one-sixth the weight of the used cupel would give a very satisfactory fusion, when melted at a slightly high temperature. The resulting lead buttons were carefully cupelled with feather litharge, the final bead being weighed and then parted for gold. The general rule followed in preparing the cupels for assay was to be sure and include all the stained portion. In doing this, more or less unstained bone ash had to be taken. A large amount of the unstained ash required the larger amount of cryolite. In later work with heavier cupels, more flour was required.

In this preliminary test, six sets of nine cupels (54) from each one of five laboratories were assayed in the Bureau laboratory. This made a total of 270 cupels, but for various reasons eight assays were lost, leaving a total of 262.

The details of the method of assaying followed in each laboratory are briefly summarized in Table 1.

TABLE 1.—*Fine-gold Assays*

Details of Method Used in Mint Service

Laboratory	Weight					Proportion Gold to Silver	Cupellation		Annealed, Times	Acid B°	Boil, Minutes
	Sample, Grams	Ag, Grams	Pb, Grams	Cu, Mg.	Cupel, Grams		Temperature	Time, Minutes			
1	0 5	1.50	2	10	23–24	1:3	Good red	8–10	2	22 32 32	10 10 10
2	0 5	1.00	8	50	25	1:2	1,550° F.	18	2	32 32	10 10
3	0 5	1.00	3	5–10	20	1:2	Bright red	4–5	3	22 32	20 20
4	0.5	1.25	5	25	20	1:2.5	1,155° C.	9	1	27 32	10 10
5	0.5	1.00	2	7.5	23	1.2	High	6	2	32 32	10 10

The amount of gold absorbed at the laboratories No. 1, 2 and 3 varies widely, but shows a considerable agreement amongst themselves. Laboratory No. 4 shows very large and widely varying absorptions of gold, while the absorptions at laboratory No. 5 are very small and agree very closely. These results are shown in Table 2.

TABLE 2.—*Fine-gold Assays*

Cupel Absorption

Weight of Gold Absorbed, Mg	Cupels Assayed			Weight of Gold Absorbed, Mg.	Cupels Assayed, Laboratory 4	Weight of Gold Absorbed, Mg.	Cupels Assayed, Laboratory 5
	Laboratory						
	1	2	3				
0 20	...	...	4	....	..	0.08	1
0 21	...	...	2	0.33	1	0˙09	3
0.22	...	...	5	0.37	1	0.10	4
0.23	...	...	3	0.38	2	0.11	4
0.24	...	...	6	0.40	5	0.12	2
0.25	...	1	1	0.41	2	0.13	15
0.26	2	...	6	0.42	2	0.14	6
0.27	1	1	...	0.43	3	0.15	5
0.28	2	1	1	0.44	4	0.16	3
0.29	4	1	3	0.45	3	0.17	5
0.30	4	2	3	0.46	2	0.18	1
0.31	4	...	2	0.47	3	0.19	5
0 32	2	3	2	0.48	3		
0.33	4	...	...	0.49	3		
0.34	2	5	...	0.50	3		
0.35	5	6	2	0.51	1		
0.36	5	8	2	0.53	1		
0.37	3	5	2	0.56	2		
0.38	4	4	2	0.59	1		
0.39	1	4	1	0.60	1		
0.40	2	3	2	0.62	2		
0.41	1	1	1	0.63	1		
0.42	...	...	1	0.66	1		
0.43	2	...	...	0.69	2		
0.44	2	1	...	0.71	1		
0.45	2	2	1	0.72	1		
0.46	...	1	.	0.78	1		
0.48	...	1	...	0.83	1		
0.49	1						
Total..........	53	50	52	....	53	....	54

The amount of silver absorbed by the cupels shows an astonishing variation and for the present simply the highest and lowest amounts in each set are given, in Table 3.

This set of cupel assays was made for the purpose of getting a general preliminary view of the field. The 270 cupels may be taken as typical

TABLE 3.—*Fine-gold Assays*

Silver Absorbed by Cupels

Laboratory No	Mg. Highest	Mg Lowest
1	19.74	15.09
2	13 64	9.16
3	12.77	8.08
4	21.23	12 54
5	6 97	4.90

of the general practice of cupel making in the Mint service at that time. Each one had been taken from a lot that had passed all the usual visual-examination and other tests. Each one had successfully passed the test of actual use, and was therefore entitled to be called a good cupel. Consequently, the determination of the amount of gold absorbed by each cupel should give a set of typical figures.

It was fully appreciated that the cupel absorption was influenced by a variety of circumstances and that some differences could naturally be looked for, but such wide variations as the table shows were entirely unexpected. It is possible, but hardly probable, that some of the cupels contained beads. Certainly the presence of beads could not account for the variations.

The next step in the investigation was to gather a set of samples of bone ash from the various laboratories and subject them to a screen analysis. As in the case of the cupels, these samples may be taken as typical, as they present five varieties of bone ash that had been accepted by five institutions as suitable for making cupels and had been used for that purpose. It would have been better if we could have tested the actual bone ash used in making the cupels assayed, but it was then too late for that and these screen analyses simply give a general idea of the practice at each laboratory.

Table 4 gives these screen analyses, together with the screen analysis of the bone ash at that time in use in the Bureau laboratory. This ash

TABLE 4.—*Screen Analysis of Bone Ash*

Averages of Two 10-Oz. Samples in Each Case

Laboratory	No. 1, Per Cent	No. 2, Per Cent	No. 3, Per Cent.	No. 4, Per Cent.	No. 5, Per Cent.	No. 6 Bureau, Per Cent.
On 20-mesh...	....	0.15	.....	Traces	.....	Traces
On 40-mesh...	1.5	7.75	2.75	7.5	Traces	1.25
On 60-mesh ..	12.5	5.75	3.50	12.5	0.5	4.25
On 80-mesh...	12.5	15.00	8.00	17.5	6.0	19.00
On 100-mesh...	16.5	6.50	4.25	7.5	4.0	7.25
Through 100-mesh...	57.0	65.75	81.50	55.0	89.5	68.25

had been obtained from laboratory No. 1. It is therefore shown that considerable variation might occur in the screen analysis of the ash as used at a single laboratory at different times.

In making screen analyses of bone ash, it is absolutely essential that the samples be thoroughly dry. This requires prolonged exposure to a gentle heat, preferably a little above 100° C.

In order to further test the question, this table of screen analyses was submitted to the five laboratories without specifying the sources of the bone ash or informing them of the results of assaying the cupels, and each one was asked to select the best ash in their judgment for making cupels. Laboratory No. 1 declined to commit itself; No. 2 selected ash No. 4 which had given the worst results in the assay tests; No. 4 selected ash No. 1, and Nos. 3 and 5 selected both No. 3 and No. 5 ash.

Each laboratory supplied a full and complete description of its methods of securing what was considered a proper bone ash and of manufacturing the cupels. The tests applied to the bone ash had been crude and empirical. One assayer said: "The best test we can make with new ash is the practical working, that is making a large number of assays (proofs), making a careful examination of the cupels and of the resulting assays." Another said: "The tests applied to the bone ash when purchasing have been simply to specify the grade, and when it has been received to see that it is clean, being free from dirt, and passing it through the hand to see if it feels all right, and if it will make a firm smooth cupel. The cupels after drying are tried out in the muffle to see if they absorb the lead and do not check or crack, and if they hold up the bone ash is accepted." A third assayer sifted the ash through 60-mesh and if more than 4 per cent. remained rejected the sample. A fourth assayer said: "I apply no special tests to bone ash beyond inspecting and handling it. If it does not make a satisfactory cupel I reject it."

The method of making cupels is very simple and substantially the same at each institution. The bone ash is moistened, generally with water only, until it will cohere into a lump on gentle pressure in the hand. After being allowed to stand, it is fed into a mold, a plunger is applied to form the cupel, and the finished cupel is removed from the mold. Different styles of machines, both hand and power, are used to form the cupel and different pressures are applied. The size, shape, and weight of the cupel vary, but, owing to the wide variation shown in the amount of gold absorbed when the cupels were used, it scarcely seemed worth while to go into a discussion of these details at this stage of the investigation, although they were of considerable value in carrying on the work.

Owing to the very large button of gold and silver obtained in assaying gold bullion, the question of the smoothness of the surface of the cupel is not quite so important as it is in the assaying of ores where minute buttons are obtained, but the surface must be fairly smooth.

TABLE 5.—*Bone-Ash Screen Analysis, Laboratory No. 4*

		1	2	3	4	5
On	40..	....	....	7.5	1.0	
	60..	17.5	....	12.0	5.5	
	80	14.5	14.0	11.5	6.5	
	100..	10 5	14.5	11.5	10.5	
Through	100..	57.0	71.0	57.0	76.0	All
		99.5	99.5	99 5	99.5	100.0

TABLE 6.—*Gold Absorption*

Special Cupels, Made and Assayed at Laboratory No. 4

	No. 1 Ash		No. 2 Ash	No. 3 Ash
Gold Absorbed, Mg.	Cupels Assayed	Gold Absorbed, Mg.	Cupels Assayed	Cupels Assayed
0.19	1	0.23	..	2
0.20	2	0.25	..	2
0.21	..	0.26	1	
0.22	1	0.27	1	1
0.23	3	0.28	1	
0.24	1	0.29	1	1
0.25	1	0.30	2	1
0.26	..	0.31	..	1
0.27	4	0.32	2	4
0.28	1	0.33	2	2
0.29	1	0.34	2	2
0.30	5	0.35	4	1
0.31	10	0.36	2	2
0.32	3	0.37	4	4
0.33	5	0.38	3	8
0.34	1	0.39	..	3
0.35	3	0.40	5	4
0.36	1	0.41	4	
0.37	2	0.42	3	3
0.38	..	0.43	1	4
0.39	..	0.44	1	3
....	..	0.45	3	
....	..	0.46	2	2
....	..	0.47	..	1
....	..	0.48	..	1
....	..	0.49	..	2
....	..	0.50	1	1
....	..	0.51	..	1
....	45	....	45	56

A casual inspection of the cupel absorption table suggests that the cupels made in laboratory No. 4 were unreliable and in need of improvement. New cupels were therefore made from five different samples of bone ash shown by the screen analyses in Table 5.

Cupels made from No. 1 and 2 ash, 45 of each, and 56 cupels made from No. 3 ash, were used in assaying very fine gold, 0.5 gram, and the used cupels were assayed for gold and silver. Table 6 summarizes the gold figures obtained.

While these gold absorptions agree better than the first set from No. 4 laboratory, yet most of them are much too high.

Cupel No. 1 and 2 were used in sets of nine each, No. 3 in sets of nine and ten, the proportion of silver to gold being $2\frac{1}{2}:1$. Table 7 shows the highest and lowest silver absorption found in each set.

TABLE 7.—*Silver Absorptions*

Special Cupels, Made and Assayed at Laboratory No. 4, Used in Sets of Nine and Ten. Weight of Silver Absorbed in Mg.

Ash	High	Low	High	Low	High	Low	High	Low	High	Low			Totals		
													High	Low	Diff.
1	13.98	12.16	13.97	12.67	13.11	9.81	14.53	13.49	13.13	10.28	.....	.....	14 53	9 81	4.72
2	15 14	13.03	14.72	13 15	14.23	13.15	15.15	12.33	16.83	13.08	....	....	16.83	12.33	4.50
3	14.77	13.08	14.25	11.07	16 12	15.16	16.42	14.67	15.38	13.22	14.05	12.68	16.43	12.68	3.74

Cupels made from ash No. 4 were tested in assaying standard coin gold, 900 gold and 100 copper with a trifle of the copper replaced by silver, 0.5 gram being used for the assay. They were tested in 12 sets of ten each under varying conditions. At this time all the absorption results will be grouped together, leaving the discussion of the effect of the varying group conditions until later.

TABLE 8.—*Gold Absorption*

Special Cupels, Made and Assayed at Laboratory No. 4 Used on Coin Gold

	Gold Absorbed, Mg.	Cupels Assayed	Gold Absorbed, Mg.	Cupels Assayed
	0.12	4	0.21	8
	0.13	8	0.22	4
	0.14	7	0.23	4
	0.15	5	0.24	3
Total cupels assayed 119	0.16	5	0.25	5
	0.17	19	0.26	4
	0.18	18	0.27	3
	0.19	8	0.28	1
	0.20	11	0.29	2

Table 9 shows the highest and lowest silver absorption found in each set of ten cupels. The proportion of silver to gold in the coin assays was $2\frac{1}{2}:1$.

TABLE 9.—*Silver Absorption*

Special Cupels, Made from Ash No. 4, Used in Sets of Ten on Coin Gold and Assayed at Laboratory No. 4. Weight of Silver Absorbed in Mg.

High	Low	High	Low	High	Low	Totals		
						High	Low	Diff.
10.79	8.88	10.39	8.05	12.31	10.07	12 69	6.75	5.94
10 02	8.22	11.11	9.38	11.57	9.32			
12.21	8.96	9.10	7.68	10.45	7.70			
12.09	10.46	9.38	6.75	12.69	9.38			

Only a single set of ten cupels made from ash No. 5, all of which passed 100-mesh, was used on coin gold, 0.5 gram, silver to gold $2\frac{1}{2}:1$, with the results shown in Table 10.

TABLE 10.—*Cupels, Made from 100-Mesh Ash, Used on Coin Gold and Assayed at Laboratory No. 4*

Gold Absorbed, Mg.	Silver Absorbed, Mg.
0.25	12.16
0.25	12.12
0.25	10.96
0.21	11.01
0.29	12.96
0.26	11.79
0.25	11.70
0.26	12.67
0.25	11.75
0.27	11.71

From necessity, the preliminary work of investigating cupel absorption in the Mint Bureau laboratory had to dovetail into the regular work of assaying in that laboratory. This work was then very largely on coins and included but little fine-gold assaying.

Owing to the presence of copper in coin gold and the consequent necessity of using more lead and a higher temperature in assaying, the absorptions in coin-gold assaying are not directly comparable with the absorptions in fine-gold assaying. Table 11, however, serves as a connecting link between the table of preliminary fine-gold-assay absorptions and the subsequent investigations on coin-gold absorptions in the Bureau laboratory. This table summarizes 32 coin-gold assays made in labora-

tory No. 5 and a set of nine coin-gold assays made in the Bureau laboratory in cupels made from a very fine ash of the following screen analysis:

	Per Cent
On 60-mesh	0.5
80-mesh	6 0
100-mesh	4.0
Through 100-mesh	89.5

All the cupels were assayed in the Bureau laboratory.

TABLE 11.—*Gold Absorptions*

Coin-gold Assays

Gold Absorbed, Mg	No. 5 Laboratory Cupels, No. Assayed	Bureau Laboratory Cupels, No. Assayed
0.14	1	1
0.15		
0.16	2	2
0 17	..	3
0 18	4	1
0.19	2	1
0.20	4	1
0.21	5	
0.22	2	
0.23	2	
0.24	2	
0.25	2	
0.26	3	
0.27	1	
0.28	1	
0.29		
0.30	1	
Total	32	9

Although not strictly comparable, I insert here tests of two commercial cupels of American make, used in assaying coin gold in the Bureau laboratory:

TABLE 12.—*Gold Absorption*

Commercial Cupels Coin-gold Assays

Gold Absorption, Mg	Cupel A, No. Assayed	Gold Absorbed, Mg.	Cupel B, No. Assayed
0.13	1	0.19	1
0.14	1	0.22	1
0.15	2	0.23	2
0.17	1	0.24	1
0.18	2	0.26	1
0 20	1	0 30	1
0.21	1	0.32	1
0.22	1	0.33	1
0.23	1	0.34	1
0.26	1	0.37	1
0.28	2	0.38	1
0.29	1	0.39	3
0.31	1	0.41	1
0.32	2	0.43	1
		0.45	1
	18	....	18

Four special samples of bone ash prepared in the Bureau laboratory and two samples of a commercial brand of bone ash yielded the figures shown in Table 13 on screen analysis.

TABLE 13.—*Bone Ash, Screen Analysis*

	Bureau Samples				Commercial Samples	
	I, Per Cent.	II, Per Cent.	III, Per Cent.	IV, Per Cent.	V, Per Cent.	VI, Per Cent.
On 40-mesh......	.....	.....	.....	....	2.5	2.0
On 60-mesh.....	.....	.....	5.0	....	8.0	7.0
On 80-mesh.....	14.5	13	16.5	15	15.5	14.0
On 100-mesh......	10.0	5	5.5	8	3.5	2.5
Through 100-mesh.....	75.5	82	73.0	77	70.5	74.5
	100.0	100	100.0	100	100.0	100.0

Cupels made from each of these samples of bone ash were used in the Bureau laboratory in assaying coin gold under varying conditions in groups, generally of nine. As before, the discussion of the effect of the group variations is reserved until later and all the absorptions of each type of cupel are summarized in Table 14.

TABLE 14.—*Coin-gold Absorptions*

Special Cupels Made, Used and Assayed at the Bureau Laboratory

Gold Absorbed, Mg.	Ash No. 1	Ash No. 2	Ash No. 3	Ash No. 4	Ash No. 5	Ash No. 6
0.09	..	..	..	..	..	1
0.10	1	..	..	..	..	2
0.11	4	..	..	.	..	2
0.12	2	..	..	.	.	3
0.13	2	..	..	1	2	1
0.14	2	2	1	2	2	
0.15	6	2	4	2	5	2
0.16	10	5	4	3	7	8
0.17	5	5	4	5	4	6
0.18	9	3	6	4	5	16
0.19	8	6	4	7	6	8
0.20	3	5	4	3	6	2
0.21	2	5	2	.	2	2
0.22	..	2	3	5	3	
0 23	.	2	3	3	1	
0.24	1	4	..	..	3	
0 25	..	3	..	..	1	
0.26	..	..	..	..	2	
	55	44	35	35	49	53

The silver absorptions for three sets of nine assays for each ash are summarized in Table 15, the proportion of gold to silver used being 1:2.25.

TABLE 15

Ash	High	Low	High	Low	High	Low	Totals		
							High	Low	Diff
1	10.44	8.85	8.82	8.08	9.65	8.18	10.44	8.08	2.36
2	10.71	9.33	9 61	8.47	9.18	7.39	10.71	7.39	3.32
3	10.20	8.77	9.05	7.31	10.37	9.09	10.37	7.31	3 06
4	8.52	6.53	10.13	8.92	10 65	8.98	10.65	6.53	4.12
5	10.97	8.96	9.01	7.47	9.00	7.74	10.97	7.47	3.50
6	9.68	8.15	7.15	5.07	9 86	7.77	9.86	5.07	4.79

However, a change in the coinage laws, permitting the issue of gold certificates against gold bars as security, brought more fine-gold[4] assaying

[4] In the mint service the term "fine gold" is applied to any metal over 992 fine in gold. It is purely arbitrary and sometimes unsatisfactory. It does not take into account the character of the balance of the metal and is occasionally applied to brittle bullion which needs refining. In this paper, however, it always means ductile fine gold.

to the Bureau laboratory, and later much work was done on cupel absorptions with this metal.

For nearly 4 years, almost all the cupelling done in the Bureau laboratory was directed toward elucidating some point regarding cupels. Besides this, many runs, both regular and special, were made in other laboratories in the service and the cupels were forwarded to the Bureau to be assayed. Also, one service laboratory made many tests and assayed the cupels themselves. In all, about 100 varieties of bone ash have been tested, and probably 10,000 or more used cupels have been assayed. The result of this investigation is a most emphatic warning against drawing conclusions regarding cupels and cupellation from insufficient data. From the vast accumulation of data now on hand, I can pick out isolated illustrations here and there to support any reasonable supposition and also a great many unreasonable and contradictory ones regarding the subject. Again I can pick out many apparent exceptions to every general rule.

The second result is to emphasize the difficulty of carrying on several sets of cupellations under even approximately the same conditions. I have tried many times to work out the effect of some chief factor in the operation to find it impossible in the end to draw rigid conclusions on account of the disturbance caused by some minor factor, which, under the circumstances, was often beyond control. It was no unusual thing for such tests to yield confusing and contradictory results. This is due to the practical difficulties of arranging and controlling the contradictory and interdependent conditions in making successive sets of cupellations.

The third result is that rigid conclusions regarding bone ash, cupels and cupellation call for such a vast amount of painstaking detailed work under such onerous conditions that the game is scarcely worth the candle, especially as the customary variations occurring in practical work will nullify many such conclusions.

Finally, then, the results of this work cannot be dealt with in any dogmatic way, but they must be applied in a general and practical way with reasonable consideration and caution.

It is, for instance, most undoubtedly true that high temperature increases cupel absorption, other things being equal, but it is seldom that all the other things are equal and it is often impossible to tell wherein they vary. It is perfectly reasonable to assume that the back part of a muffle is hotter than the front. In fact, as long ago as 1891 Roberts-Austen[5] reported determinations by T. K. Rose showing that the back of the muffle in the British Mint was from 50° to 60° hotter than the front and that there was a difference of approximately 5° between the rows of cupels. Yet every experienced bullion assayer at times finds the loss in weight in the back cupels less than in the accompanying front

[5] *Twenty-second Annual Report, Deputy Master of the Mint* (British), 1891, 69.

ones. The same thing appears in the cupel absorption of gold and silver, and in the illustrations given below there are many instances where a cupel absorbed less than those in front of it.

It is also self-evident that the porosity of the cupel should exert an important influence on the absorption of gold. It goes without saying that cupels should possess a proper porosity, but in the vast majority of cases very little, if any, real information has been given by writers upon assaying as to just what proper porosity may be. It is generally described in some vague way as "not too fine and not too coarse."

Two screen analyses of commercial bone ash are given by Lodge,[6] which "give some idea of the bone ash on the market as passing a 40-mesh screen," but he gives no indication of the value, relative or otherwise, of the two samples. Fulton[7] gives "a screen analysis of the bone ash commonly purchased, but which is rather coarse." These three screen analyses are shown in Table 16.

TABLE 16

	Per Cent.	Per Cent.	Per Cent.
On 30-mesh...	....	....	2.00
40-mesh....	0.5	0.9	6.40
60-mesh....	3.0	26 2	10 04
80-mesh....	15.9	19.2	2.00
100-mesh....	27 8	21.8	11.20
Through 100-mesh....	52 8	32 1	68.88
Total.............	100.0	100.2	100.52
Authority..........	Lodge		Fulton

It should also be noted that the pressure used in making a cupel influences the porosity.

As a general proposition, cupels must absorb the PbO as formed, but this is not governed solely by the porosity of the cupel. Size of buttons, temperature and degree of saturation of the cupel are important factors in absorption. Even yet I am not prepared to define, except in a most general way, and largely as a matter of opinion, either a maximum or

[6] R. W. Lodge: *Notes on Assaying and Metallurgical Laboratory Experiments*, 19. N. Y., John Wiley & Sons, 1904,

[7] C. H. Fulton: *Manual of Fire Assaying*, 77. N. Y., McGraw-Hill Book Co.., 1911.

minimum desirable degree of porosity because the following tests show that its influence in bullion assaying may be so easily overbalanced by other conditions.

Three grades of cupels were made from five different bone ashes by the application of different pressures in making the cupels. The soft ones were made on a hand press. The standard ones were made on a power press at the usual pressure and the hard ones at a greater pressure.

In general, 18 assays, in two sets of nine each, were made in the Bureau laboratory on each kind of cupel on coin gold, with 4 grams of lead and 2.25 parts of silver to 1 of gold; the cupellation generally occupying from 9 to 11 min. from the time the last packet went into the cupel to the time the first cupel was removed from the furnace. Several cupel assays were lost and one group is short a set of nine. The results are summarized in Table 17.

TABLE 17.—*Cupels Assayed*

Gold Absorbed, Mg.	Ash No. 1			Ash No. 2			Ash No. 3			Ash No. 4		
	Soft	Std.	Hard	Soft	Std.	Hard	Soft	Std.	Hard	Soft	Std.	Hard
0.09	...	4	1									
0.10	...	5	1									
0.11	2	3	5	...	...	3	2	...	1			
0.12	7	4	7	4	...	...	4	3	2			
0.13	5	...	2	6	2	1	7	3	2	1	1	1
0.14	3	...	2	4	2	7	3	6	...	1	1	3
0.15	...	...	...	...	2	4	2	2	3	6	3	2
0.16	...	...	...	1	3	3	...	3	1	6	4	4
0.17	...	...	...	...	4	...	...	...	2	3	4	4
0.18	...	...	...	...	4	...	...	...	4	...	3	4
0.19	...	...	...	...	...	...	...	1	1	...	1	
0.20	...	...	...	...	...	...	...	...	2			
0.22	...	...	...	...	...	...	...	...	...	1		
Total....	17	16	18	15	17	18	18	18	18	18	17	18

The fifth set yielded some very peculiar results. Unfortunately, only one set of nine was run on the soft cupel. In one set on the standard cupel the time was only 8 min., indicating a somewhat hotter muffle, and the same fact is reflected in the absorptions as only one is 0.14 mg. and all the rest of this set of nine are above 0.14 mg. The low results given by the hard cupel are also noticeable. Table 18 summarizes the results.

TABLE 18.—*Cupels Assayed*

Gold Absorbed, Mg.	Ash No 5.		
	Soft	Std	Hard
0.09	...	...	3
0.10	...	...	3
0.11	1	1	
0.12	2	1	3
0.13	2	3	5
0.14	2	5	2
0.15	1	2	2
0.16	1	3	
0.17	...	3	
Total....	9	18	18

These five ashes showed the following screen compositions.

TABLE 19

Ash	No 1, Per Cent.	No. 2, Per Cent.	No. 3, Per Cent.	No. 4, Per Cent.	No. 5, Per Cent.
On 40-mesh	1.0	1.0	2		
On 60-mesh	2.5	8.5	7	9.75	7.0
On 80-mesh	15.5	14.0	16	15.75	12 5
On 100-mesh	3.0	5.5	6	6.00	5.5
Through 100-mesh	78.0	71.0	69	68.50	75.0
	100.0	100.0	100	100.00	100.0

Laboratory No. 4 prepared some "very soft" and "soft" cupels from an ash of the following screen analysis:

	Per Cent.
On 40-mesh............................	7.5
On 60-mesh	12.0
On 80-mesh	11.5
On 100-mesh................	11.5
Through 100-mesh................	57.0
	99.5

Each cupel was used in four sets of nine each in assaying fine gold with the results shown in Table 20.

TABLE 20.—*Cupels Assayed*

Gold Absorbed, Mg.	Very Soft	Soft
0 27	1	
0.32	1	
0.33	1	
0 34	2	
0.35	1	1
0.36	1	1
0.37	2	6
0.38	5	7
0.39	2	5
0.40	4	7
0.41	..	3
0.42	3	1
0.43	4	1
0.44	2	
0.45	..	1
0.46	2	
0.47	1	1
0.48	1	1
0.49	1	
0.50	1	
0.51	1	
Total	36	35

The most diverse practice obtains as to the time cupels should stand and season before being used. In the British Mint it is, or was, the practice to season cupels for 2 years. On the other hand, a very experienced assayer has told me that absolutely no seasoning is required provided care is exercised in drying out new cupels in the furnace. If in a hurry he does not hesitate to take freshly pressed cupels, dry them carefully, and use them within a few hours of pressing.

Laboratory No. 4 combined some of its porosity tests with age tests. Sets of ten cupels each, of soft and hard cupels, were used in assaying standard gold when 1, 2, 3, and 5 days old. The used cupels were assayed with the results shown in Table 21, the soft cupels 1 day old giving the lowest absorption.

TABLE 21.—*Cupels Assayed*

Gold Absorbed, Mg	1 Day Old		2 Days Old		3 Days Old		5 Days Old	
	Soft	Hard	Soft	Hard	Soft	Hard	Soft	Hard
0.12	1							
0 13	1							
0.14								
0.15	1	...	...	...	2			
0.16	1	...	..	...	2	1	...	
0 17	2	3	...	...	4	3	...	2
0.18	2	5	. .	...	1	4	...	1
0.19	1	1	...	1	1	...	...	1
0.20	...	...	...	...	...	...	1	4
0.21	1	1	...	1	...	1	3	1
0.22	...	...	1	...	...	...	2	1
0.23	...	...	1	2	...	1		
0 24	...	...	...	1	...	...	2	
0.25	...	...	2	1	...	...	2	
0.26	..	...	3	1				
0 27	...	...	2	1				
0.28	...	...	...	1				
0.29	...	...	1	1				
Total....	10	10	10	10	10	10	10	10
	Silver Absorbed, Mg.							
Highest.........	10.79	10.02	12.21	12.09	10.39	11.11	12.31	11.57
Lowest..........	8.88	8.22	8 96	10.46	8.05	9.38	10.07	9.32

These cupels were made in a power press from ash of the following screen composition:

	Per Cent.
On 40-mesh..............................	1.0
On 60-mesh..............................	5.5
On 80-mesh..............................	6.5
On 100-mesh........................... ..	10:5
Through 100-mesh..............................	76.0
	99.5

Laboratory No. 5 used two different cupels when 2, 8, 21, and 40 days old, in sets of nine in assaying coin gold. The used cupels were assayed at the Bureau with the following results:

TABLE 22.—*Cupels Assayed*

Gold Absorbed, Mg.	2 Days Old		8 Days Old		21 Days Old		40 Days Old	
	No 1 Ash	No 2 Ash	No 1 Ash	No. 2 Ash	No 1 Ash	No 2 Ash	No. 1 Ash	No 2 Ash
0.14	..	1	..	..	2			
0 15	..	1	2	..	4			
0.16	3	3	3	5	3	1		
0.17	4	3	2	2	..	3	4	1
0.18	2	1	2	1	..	2	2	1
0.19	..	..	..	1	..	3	2	2
0.20	..	..	..	..	..	..	1	3
0.21	..	..	..	..	..	..	..	1
0.22	..	..	..	..	..	..	..	1
Total...	9	9	9	9	9	9	9	9
Silver Absorbed, Mg.								
Highest.........	8 78	8.15	9.62	8.93	8.56	8.50	10.68	11.59
Lowest..........	7 28	6.73	7.26	6 84	6.86	7.06	8.02	8.30

These cupels were made on a foot press from ashes of the following screen analysis:

TABLE 23

	No 1, Per Cent.	No. 2, Per Cent.
On 40-mesh.................	2	
On 60-mesh.................	5	5
On 80-mesh.................	15	10
On 100-mesh.................	8	10
Through 100-mesh.................	70	75
	100	100

In the Bureau, sets of nine cupels were run at 2, 8, 9, 17, and 33 days on coin gold with 4 grams of lead and 2.25 parts of silver to 1 part of gold. The 9-day run was a temperature test rather than an age test and the muffle was about as cool as it was possible to have it safely. The absorptions are, therefore, low. A second set was run at 33 days with the furnace perceptibly hotter than on the first run, and this fact shows in the absorptions.

Table 24 summarizes the results.

TABLE 24.—*Cupels Assayed*

Gold Absorbed, Mg.	2 Days	8 Days	9 Days	17 Days	33 Days	33 Days
0.09	..	..	1			
0.10	..	.	2			
0.11	..	..	2			
0.12	..	..	3			
0.13	..	..	1			
0.15	1	..	.	..	1	
0.16	1	3	.	3	..	1
0.17	..	2	..	2	2	
0.18	4	4	..	4	2	2
0.19	3	..	..	..	2	3
0.20	..	..	..	..	1	1
0.21	..	..	..	..	..	2
Total.......	9	9	9	9	8	9
Silver Absorbed, Mg.						
Highest................	9.63	9.86	7.15	9.18	9.99	10.34
Lowest....	8.15	7.77	5.07	7.39	8.33	9.17

These cupels were made on a hand machine from bone ash of the following screen analysis:

	Per Cent.
On 40-mesh..	2.0
On 60-mesh....	7.0
On 80-mesh..............	14.0
On 100-mesh....	2.5
Through 100-mesh............................	74.0
	99.5

It is a fair general inference from these porosity and age tests that in bullion assaying the porosity may vary greatly and that no seasoning of the cupels is required.

In considering the question of the amount of precious metals shown by assaying used cupels it must not be forgotten that distinct beads of precious metals sometimes remain on the surface of the cupels. Manifestly these must not be considered as part of the absorption. This point has been carefully watched and as far as possible beaded cupels have been eliminated from the tables or their presence noted. With the great care exercised, however, it is evident that at times the results are vitiated by minute beads. When, for instance, one cupel in a set of nine or

twelve shows abnormally high results it is fair to assume that beads were present which escaped detection before assaying the cupel.

The question of the cause of beads in cupels is worthy of careful and systematic study, but it is rather difficult to work out because there is now no known means of telling when beads are likely to form in regular work, and when they are found at the end of the operation it is too late to detect the cause, in most instances, with any certainty. At this time I wish simply to mention particularly one phase of the beaded condition that affects some of the comparisons dealt with in this paper. This is that small separated beads may differ widely in composition from the main button. Thus, when the packet is melting down, a particle of bullion may get separated on the side of the cupel before becoming alloyed with any silver, while also a particle of silver may get separated before alloying with any gold. Partial alloys may also separate as beads. When the metals are thoroughly alloyed, any bead that may separate should be of the same composition as the main button.

When, for instance, one cupel in a set of nine or twelve shows an excessive amount of gold as compared with the surrounding cupels, it is a fair assumption that a bead high in gold has separated. The same reasoning would apply to silver, but the excess of silver must be very much greater to warrant the assumption of the separation of a bead rich in silver, on account of the greater amount absorbed and wider variations naturally shown. When, however, such a cupel shows an excess of both gold and silver, it is fair to assume that a bead separated after alloying of the metals.

In a set of four rows of four cupels each used in assaying standard gold, 15 of the gold absorptions varied from 0.47 to 0.57 mg. while the silver absorptions varied from 19.50 to 23.35 mg. The sixteenth cupel, however, showed a gold absorption of 0.87 mg. while the silver absorption was 21.30 mg. Evidently a minute bead of gold separated in this cupel. In a row of three cupels used on crude bullion, the figures indicate the separation of a bead of bullion by the following absorptions in milligrams:

Gold 0.54; silver 7.02. Gold 0.84; silver 8.25. Gold 0.51; silver 6.78.

In three rows of three cupels the separation of beads of fully alloyed metal is indicated by the following absorptions in milligrams.

No. 1		No. 2		No. 3	
Gold	Silver	Gold	Silver	Gold	Silver
0.20	17.17	0.33	8.73	0.24	9.40
0.13	14.06	0.24	7.58	0 23	8.73
0.12	13.46	1.38	14 17	0.70	10.92

Owing to the very high proportion of silver in the button, from bullion assay cupels, the gold often separates in a finely divided state on parting. Even with the utmost care, a minute amount may be lost in decanting the nitrate of silver solution. Some of the discrepancies shown in the comparisons may be due to the loss of 0.01 mg. or possibly 0.02 mg. from this cause. This weight is only a very minute volume of gold. The general tendency of cupel assays is to give low results rather than high ones.

It very soon became evident in our investigations of cupels that the question of the temperature of cupelling was a most important one. It is the most troublesome variable in assaying. It is the most difficult condition to control and to duplicate. It is probably the most potent factor in its effect on cupel absorption. At any rate, small differences of temperature may at times reverse the relative normal rate of absorption. The temperature that controls the results and success of a cupellation is the temperature of the cupelling lead button. There is no method available for determining this temperature and it may vary in adjoining cupels. It is entirely different from any pyrometer reading that can be ascertained in practical work. In a vast majority of cases, there is no relation between the two temperatures. The pyrometer reading may be maintained practically uniform while the actual temperature of the cupelling buttons may vary greatly from time to time during a cupellation. Probably the chief cause of variation between the two temperatures lies in the amount of oxygen supplied to the cupelling bead, which is influenced both by the natural draft conditions of the muffle and the freedom with which air is allowed to enter the muffle. Again, it takes an appreciable time for changes in the heat conditions to show their effect upon the pyrometer couple while the same changes may instantly affect the temperature of the button. In working with a closed muffle door, for instance, the opening of the door will instantly cool the cupelling bead by the inrush of cold air. On again closing the door the bead temperature will rise, but if the open door continue a short time only the cooling effect may not appear on the pyrometer until after the closing of the door and we will have the anomalous condition that while the temperature of the bead is rising the pyrometer reading is actually falling.

In the early stages of coin work, it looked as though certain cupels were distinctly better for this class of work than others. At that time it seemed that a small quantity of 40-mesh stuff in the ash was essential to the best work. As more data accumulated, this conclusion was weakened and was finally entirely abandoned. Table 25 summarizes the results on 624 cupels used on coin gold and made from 12 varieties of ash of widely varying screen composition, No. 1 containing 2 per cent. of 40-mesh, No. 2 all passing 40-mesh and No. 3 all passing 60-mesh.

Table 25.—*Gold Absorption in Various Cupels*

	1	2	3	4	5	6	7	8	9	10	11	12	Totals
0.09	1	...	...	...	...	...	...	...	5	...	...	3	9
0.10	2	...	..	...	2	...	...	...	7	...	...	3	14
0.11	2	...	..	...	2	...	1	2	10	...	3	2	22
0.12	3	...	...	...	4	...	6	9	18	...	5	8	53
0.13	1	...	1	3	7	...	8	13	13	3	10	15	74
0.14	2	1	2	6	9	...	10	9	9	5	17	14	84
0.15	3	5	2	6	3	1	5	7	5	11	7	6	61
0.16	11	5	3	12	3	2	3	4	2	15	7	6	73
0.17	14	6	6	11	...	1	3	2	...	11	5	3	62
0.18	26	9	6	3	...	6	1	4	...	6	3	...	64
0.19	11	7	11	2	...	5	...	2	..	1	...	...	39
0.20	9	7	6	1	.	2	...	2	...	...	.	...	27
0.21	5	3	2	...	...	1	...	..	..	...	.	...	11
0 22	6	5	6	...	..	...	...	..	.	..	...	...	17
0.23	1	4	5	...	. .	...	...	...	...	...	...	...	10
0 24	1	1	1	...	. .	...	...	...	...	...	...	...	3
0.25	...	. .	1	...	..	...	...	...	...	...	...	...	1
Totals.........	98	53	52	44	30	18	37	54	69	52	57	60	624

The original coin assays were made under usual conditions, but with better observation and closer control of these conditions than is generally exercised. In several cases, the same cupel gave higher absorptions under different conditions, showing conclusively that the conditions of the cupellation had more influence on the absorption than the character of the cupels. This is strengthened by the fact that, on selection, sets of nine assays, three rows of three each, did not exceed an average absorption of 0.13 mg. per cupel on 11 varieties of ash. On raising the average to a bare trifle above 0.19 mg. the varieties of cupels are raised to 21. Table 26 gives the screen composition of the 21 ashes.

TABLE 26.—*Screen Analysis, Bone Ash*

Tested in Bureau Laboratory

	On 40-Mesh	On 60-Mesh	On 80-Mesh	On 100-Mesh	Through 100-Mesh
1	...	....	14.5	10.0	75.5
2	2.5	8.0	15.5	3.5	70.5
3	. .	....	13.0	5.0	82.0
4	2.0	7.0	14.0	2.5	74.5
5	...	5.0	16.5	5.5	73.0
6	...	....	14.5	8.5	77.0
7	. .	7.0	14.0	5.5	73.5
8	1.0	3.0	19.0	10.5	76.5
9	4.0	8.0	12.0	6.0	70.0
10	1.5	7.5	13.5	3.0	74.5
11	...	10.0	15.0	10.0	65.0
12	2.0	7.0	16.0	6.0	69.0
13	1.0	2.5	15.5	3.0	78.0
14	. .	9.5	16.0	6.0	68.5
15	1.0	8.5	14.0	5.5	71.0
16	...	7.0	12.5	5.5	75.0
17	...	8.0	8.5	9.5	64.0
18	Tr.	5.0	16.5	11.5	67.0
19	1.0	9.0	15.5	6.5	68.0
20	2.5	10.0	14.0	7.5	66.0
21	4.0	6.0	17.0	5.5	67.5

On the other hand, variations in the conditions, which were within the ordinary limits, at times brought the average up to 0.30 mg.

Many direct comparisons were made by running two or three varieties of cupels in the same set. Most of these showed practically uniform absorptions. One set of twelve, three rows of four, using three cupels gave the characteristic figures in Table 27.

TABLE 27

	Au	Ag	Ratio	Au	Ag	Ratio	Au	Ag	Ratio	Au	Ag	Ratio
1st row..	0.15	10.91	73	0.20	10.78	54	0.16	10.66	67	0.15	11.18	75
2d row..	0.19	12.83	68	0.21	12.95	62	0.19	12.81	67	0.19	12.92	68
3d row..	0.22	13.15	60	0.21	13.01	62	0.21	13.17	63	0.22	13.04	59

The fact that the conditions are more potent than the structure of the cupel is shown in a negative way by the silver absorptions. In sets showing low and uniform gold absorptions, the silver results vary greatly. There is an entire lack of relation between the gold and silver absorptions under normal conditions. In Table 27, the gold absorptions varied from

0.15 to 0.22 mg. while the silvers varied from 10.66 to 13.17 mg. and the parts of silver absorbed per part of gold varied from 59 to 75.

Coin gold was run in 21 sets of twelve cupels, three rows of four each, and five kinds of cupels were employed. The general condition of the work may be taken as typical and the variations in the conditions as being within the limits of ordinary practice.

The assay of one cupel was lost entirely. Of the remaining 251 assays, 17 were thrown out for irregularities and these rejections were governed by the ratios on the surrounding cupels rather than by the absolute ratios shown. For instance, in one row above the gold absorptions were 0.15, 0.20, 0.16 and 0.15 mg. The ratios of gold to silver were 1 to 73, 54, 67 and 75. Therefore, this 54 ratio was thrown out although there are five other 54 ratios in the lot. There are a few exceedingly high ratios, but I have no reason to doubt them. In one row the golds were 0.12, 0.12, 0.18 and 0.10 mg. Clearly the 0.18 is excessive and was rejected. The remaining three ratios were 1 to 99, 91 and 108. In another case the golds were 0.13, 0.15, 0.11 and 0.12 mg. Rejecting the 0.15 mg. the ratios are 1 to 91, 100 and 95.

The 234 accepted assays yielded the ratios shown in Table 28, the figures stated being the parts of silver absorbed for 1 part of gold:

TABLE 28.—*Ratio of Silver to Gold Absorbed*

Parts of Silver	Times Shown	Parts of Silver	Times Shown	Parts of Silver	Times Shown
35	1	55	7	73	3
36	1	56	8	74	1
38	2	57	8	75	2
39	5	58	4	76	2
40	3	59	4	77	3
41	2	60	6	78	1
42	9	61	5	79	1
43	10	62	5	81	1
44	10	63	6	82	1
45	11	64	3	84	1
46	16	65	3	88	1
47	12	66	1	90	1
48	10	67	4	91	1
49	9	68	4	93	1
50	7	69	2	95	1
51	9	70	1	99	1
52	7	71	1	100	1
53	8	72	1	108	1
54	5	..	..	Total....	234

In the early days of the investigation, some work was done on the question of the absorption of gold by the secondary cupels. In the case

of acceptable coin- and fine-gold assays, the amount of gold absorbed by a single secondary cupel is very small and it is only by uniting several that sufficient gold for satisfactory weighing can be obtained, thus averaging the results. In the second cupelling, the ratio between the gold and silver introduces a variable uncertainty from the varying protection of the gold by the silver. Again, with a wide difference in the weight of the primary cupel there will be a corresponding difference in the weight of lead cupelled in the secondary. It is therefore apparent that much work would be required to reach any definite figures upon the subject. Two cases may be given as follows:

The stained portions of nine primary cupels weighed 49.7 grams and yielded nine buttons totaling 0.87 mg. gold and 47.65 mg. silver. The stained portions of the nine secondary cupels weighed 4.66 assay tons. Two charges of 2 assay tons each were put through and the two final buttons parted together giving 0.01 mg. gold. In the second case, the primaries weighed 133.9 grams and the buttons gave 3.94 mg. gold and 141.14 mg. silver. The secondaries weighed 5.28 assay tons and the gold from two charges of 2 assay tons each weighed 0.03 mg.

Base-metal assays of crude bullion often show the absorption of 1 mg. or more of gold and low absorptions of silver. In such cases the individual secondary cupel may give enough gold to be weighed. Eight cases yielded the results shown in Table 29.

TABLE 29

Primary Cupel Absorption, Mg.		Secondary Cupel Absorption, Mg.		Primary Cupel Absorption, Mg.		Secondary Cupel Absorption, Mg.	
Au	Ag	Au		Au	Ag	Au	
1.67	1 37	0 02−	... .	1.19	1.19	0.01−	
1.66	1.35	0.01	....	1.13	1.14	0.02−	
1.25	0.99	0.02	.... .	1.00	1.01	0.02−	
1.22	1.01	0.01	....	0.94	0.97	0.01	

To these may be added an extreme and most unusual case of beaded cupels where both the gold assay and the base metal assay cupels were heavily beaded. The six primary gold assay cupels weighed 119.1 grams and yielded 10.28 mg. of gold, and 111.35 mg. silver. The six secondary cupels showed an average absorption of 0.01 mg. gold. The six primary base metal assay cupels weighed 110.1 grams and yielded 20.07 mg. gold and 18.23 mg. silver. The secondary cupels averaged 0.03 mg. gold absorbed.

In a very broad and general way, it appears then that approximately 1 per cent. of the gold present is absorbed by the secondary cupels. In a vast majority of cases, this is too small an amount to be of any moment.

In addition to its effect upon the cupel absorption of the precious metals, the temperature of cupellation is an important question as a general proposition and among other effects it is desirable to know the proportion between the lead absorbed by the cupel and that volatilized. Ten determinations of the lead in cupels used on coin gold in two laboratories showed that from 87.5 to 97.75 per cent. of the lead used had been absorbed by the cupel. It would appear from these figures that at least 90 per cent. of the lead used ought to be absorbed.

These illustrations show most conclusively that the conditions of the cupellation are far more important in influencing the cupel absorption than the structure of the cupel. When high or erratic losses are shown the used cupel should first be examined for beads. In the absence of beads the other conditions, especially the temperature, should be carefully considered before blaming the cupel.

It is evident that the screen analysis of the bone ash used for cupel making is not a dominant factor in cupelling. However, when the best results are desired it is necessary to have some standards to work to. At a conference of Mint Service assayers, the three following screen compositions were unanimously recommended as being satisfactory for bullion work.

TABLE 30

	No. 1 Per Cent	No. 2 Per Cent.	No. 3 Per Cent.
On 40-mesh	1.5–2		
On 60-mesh	6–8	7–10	4–5
On 80-mesh	12–15	15–20	10–15
On 100-mesh	5–8	5–10	5–8
Through 100-mesh	70–75	70–75	75–80

Various manufacturers were requested to bid on supplying ash graded in substantially this way and finally a bid was accepted to supply the offices throughout the service with ash graded as follows:

	Per Cent.
On 40-mesh	0–1.5
60-mesh	5–10
80-mesh	10–15
100-mesh	7–12
Through 100-mesh	65–75

This arrangement proved unsatisfactory for reasons entirely outside the screen composition.

In the miscellaneous buying of bone ash and testing the grades supplied, it has been found that the ordinary commercial grading of ash is entirely unreliable. The Bureau tested eight lots of one grade from a

manufacturer who makes a specialty of bone ash, and obtained the screen analyses shown in Table 31.

TABLE 31.—*Screen Analysis of One Commercial Grade*

	On 40-Mesh, Per Cent.	On 60-Mesh, Per Cent.	On 80-Mesh, Per Cent.	On 100-Mesh, Per Cent.	Through 100-Mesh Per Cent.
1		10.47	17.41	29.45	42.67
2	0.14	13.12	13.31	15.01	58.42
3	Trace	8 30	18.20	9.50	63.60
4	Trace	5.00	16.30	11.50	66.70
5	0.80	8.70	14.10	5.70	70.30
6	0.10	7.30	13.80	6.50	71.70
7	0 30	7.60	13.50	5.50	72.50
8	1.70	7.50	13.30	3.00	73.90

The same condition is shown by the ash of other manufacturers.

In order to overcome this difficulty, the practice has grown up of testing the ash as purchased and mixing purchases to produce a satisfactory ash. The following illustrations are taken from the practice of the New York Assay Office where this method has given much satisfaction and is to be recommended.

An ash designated as "60–80 mesh" by the manufacturer is made the basis of operations. When a barrel is received it is sampled by the use of a "tryer" and 10 oz. used for making the screen analysis. Sometimes the barrel as received compares fairly with our contract standard given above as shown by the following:

TABLE 32

	No. 1, Per Cent.	No. 2, Per Cent.	No. 3, Per Cent.
On 40-mesh........	0.6	0.7	0.7
On 60-mesh........	4.6	5.0	4.9
On 80-mesh........	6.4	6.1	6.1
On 100-mesh........	9.0	7.2	10.1
Through 100-mesh........	78.9	80.6	77.7

These barrels were used without mixing.

This grade is, however, frequently found to be too coarse and it is then mixed with ash graded by the manufacturer as "80–100 mesh" to give a mixture satisfactory for cupel making as shown by the following examples:

TABLE 33

	Coarse, Per Cent.	Fine, Per Cent.	Per Cent.	
			2 Coarse to 1 Fine	
On 40-mesh..	1 6	0.1	1.1	
On 60-mesh..	13 0	0 2	8.7	
On 80-mesh..	14.7	1.1	10.2	
On 100-mesh..	14 8	2 0	10.5	
Through 100-mesh..	55 9	95 7	69.2	
			1½ Coarse to 1 Fine	
On 40-mesh..	7.4		4.5	A little coarse
60-mesh..	25.3	As above	15.2	
80-mesh..	11 6		7.4	
100-mesh..	10.9		7.4	
Through 100-mesh.	44.8		65.2	
			4 Coarse to 1 Fine	
On 40-mesh..	1 0	0.1	0.8	
On 60-mesh..	9.7	0.2	7.8	
On 80-mesh..	14.4	1.1	11.7	
On 100-mesh..	12.8	2.0	10.6	
Through 100-mesh..	62.1	95.7	68.8	
			1 Coarse to 2 Fine	
On 40-mesh..	3.7	0.0	1.2	
On 60-mesh..	54.3	0.0	18.1	
On 80-mesh..	18.1	0.8	6.5	
On 100-mesh..	5.4	1.3	2.6	
Through 100-mesh..	18.7	98.0	71.5	
			1 Coarse to 1 Fine	
On 40-mesh..	7.8	0.3	4.2	
On 60-mesh..	22.3	1.5	11.9	
On 80-mesh..	14.0	1.5	7.7	
On 100-mesh..	9.0	2.0	5.5	
Through 100-mesh..	46.8	94.6	70.7	
			3 Coarse to 2 Fine	
On 40-mesh..	2.8	0.0	1.68	
On 60-mesh..	24.3	0.0	14.58	
On 80-mesh..	14.7	0.1	8.66	
On 100-mesh..	14.2	0.4	8.68	
Through 100-mesh..	44.1	99.5	66.26	

Two other barrels of "60–80 mesh" were used as received and showed the following screen compositions:

TABLE 34

	No. 1, Per Cent.	No. 2, Per Cent
On 40-mesh	0.5	0.1
On 60-mesh	9 9	6.2
On 80-mesh	15.6	19.6
On 100-mesh	12.6	11.9
Through 100-mesh	61.0	62.2

These figures also show wide variations in commercial grading.

Conclusions

It is apparent that the results of this investigation cannot be reduced to any hard and fast conclusions.

In assaying high-grade products giving large assay buttons, the following general conclusions may be drawn: Within wide limits the screen composition of the bone ash is not the dominant factor in cupellation, but the assayer should inform himself as to the grades of ash available and adopt some plan in selecting or mixing his ash. In the same way, the pressure used in making cupels is not highly important, although it is well to keep it fairly uniform. There is no necessity to season cupels. In making comparative tests, the closest attention must be given to the temperature question, but the temperature of the cupelling bead is for the present beyond either measurement or control, and high general temperature in the muffle may produce wide variations in the absorption of gold in adjoining cupels. The pyrometer is a good guide to the general temperature conditions, but uniformity of pyrometer reading does not mean uniform bead temperature.

In assaying ductile fine gold, for instance, it is evident that the gold absorption by a cupel may be kept down to 0.1 mg. and need not exceed 0.2 mg. Certainly an absorption of over 0.25 mg. should not be countenanced in fine-gold assaying. That these figures are attainable in regular work is shown by the results obtained in laboratory No. 5, which is a large and busy commercial laboratory. In the case of coin gold the figures might be increased by 0.05 mg.

There is no apparent relation between the absorption of the two precious metals and much more work is required to establish facts regarding the absorption of silver.

The careful assayer should establish standards of cupellation suitable for his particular lines of work and should assay his used cupels from time to time to see that the standards are being maintained.

An Automatic Filter at Depue

BY G. S. BROOKS,* E. M., AND L. G. DUNCAN,† B. S. E. M., DEPUE, ILL.

(New York Meeting, February, 1918)

During the past few years, the Mineral Point Zinc Co. has had under consideration the improvement of various types of gas-filtering apparatus used in the removal of dust from crushing and milling plants, in the manufacture of oxide, and on blast-furnace fume and sintering furnaces. The original equipment of the various plants of the company was, of course, along lines of the standard stationary bag house. These houses required large surfaces, hand shaking, and varied only in the manner of the collection of solids and in the distribution of the gas.

Early in 1908, the first trial of a mechanical bag house was made at Nassau Plant at Depue, Ill. The duty of this installation was on dust-laden gas from a fine-crushing mill. The Printz and Rau bag machine was finally adopted and put into operation. This ingenious machine embodied what were then to us two novel features in bag-house practice:

1. An intermittent crinkling and snapping of the filtering fabric to free the meshes of solids.
2. A reversal of gas flow for a short period by a temporary connection with the suction trunk.

This equipment worked fairly well except in cold weather, when we ran into condensation troubles. Had we at that time understood more fully some of the limitations of fabric filtering work, these might well have been remedied. We were impressed by this experience, however, with the efficiency of sudden tension on the fabric under suction.

After a study had been made of some of the western blast-furnace houses using the reversal-of-flow feature, experiments were started early in 1914 with a view to developing an automatic equipment along the best lines of our past experience. The objects sought were:

1. Keeping labor out of the houses for hygienic reasons.
2. Reduction of labor costs.
3. Reduction in size of bag houses.
4. Accessibility.
5. Ability to handle relatively hot gases where required.

* Asst. Supt., Mineral Point Zinc Co.
† Acting Chief of Spelter Dept., Mineral Point Zinc Co.

Since the first house was built in 1914, eight in all have been put up. During the building of the first six, several improvements were developed and incorporated.

Beginning with an intermittent suction on a single unit of the house, a vertical snap was used, mechanically actuated. Different types of jerking tops were tried, a few similar to those in use in the West and Middle West. An attempt was made to duplicate the horizontal jerk used to such good advantage in hand shaking. In working out this feature, a top toggle snap with rods was devised which has proved a very close approximation to hand work.

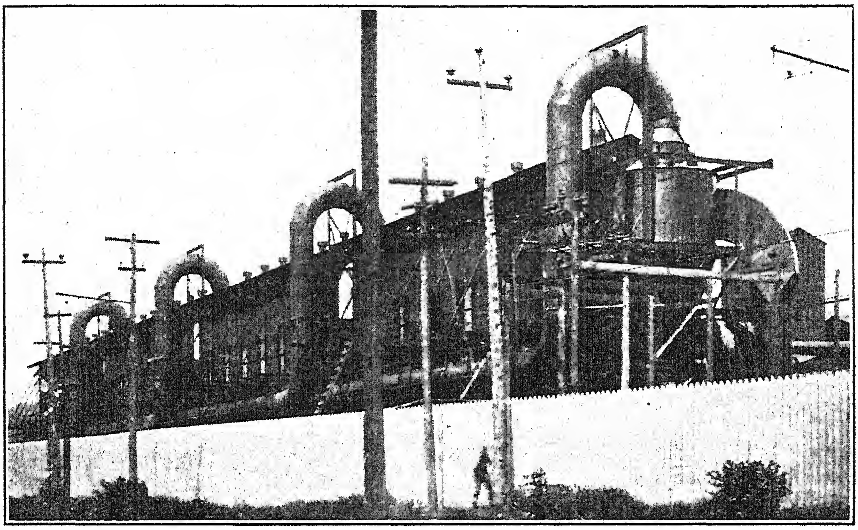

Fig. 1.—Oxide plant, Depue, Ill.

Construction

Fig. 1 shows a group of four houses, entirely automatic and filtering zinc oxide gases. It will be noted that a single fan is used with the operation of each block.

The general construction of a typical house is shown in Fig. 2, 3 and 4, while the operation of the mechanism is described in the diagrams of Fig. 5 and 6.

Sequence of Operation

The gas is delivered to the house by the cell duct 15 (Fig. 5), from whence it is led to hopper and bags through the valve opening above 18. The passage through the bags continues for a suitable interval, varying

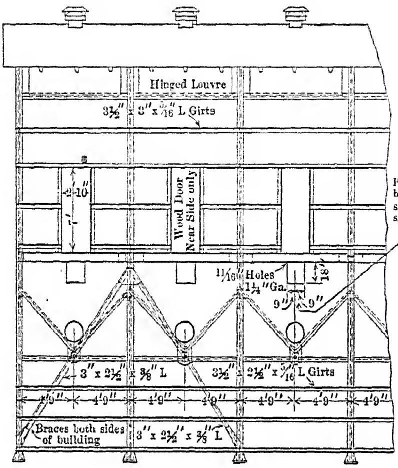

FIG. 2.

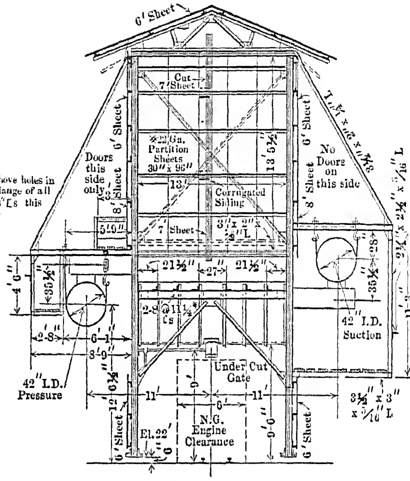

FIG. 3.

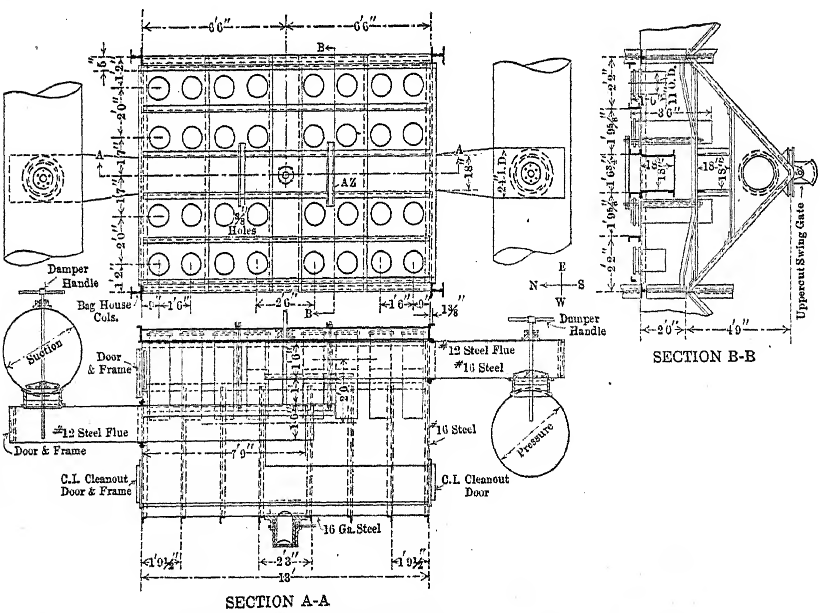

FIG. 4.

from 4 to 10 min. At the end of this time, valve 18 is automatically raised and seals pressure duct 15, at the same time opening duct 14 and thereby connecting the hopper with suction trunk flue. At this instant the bags are collapsed.

Valve 18 is actuated through rod 62 by a solenoid-controlled air lift 65. At the top limit of travel of the valve and rod, striking plate 46 engages the continuously revolving cam 47. Striking plate 46 and lever

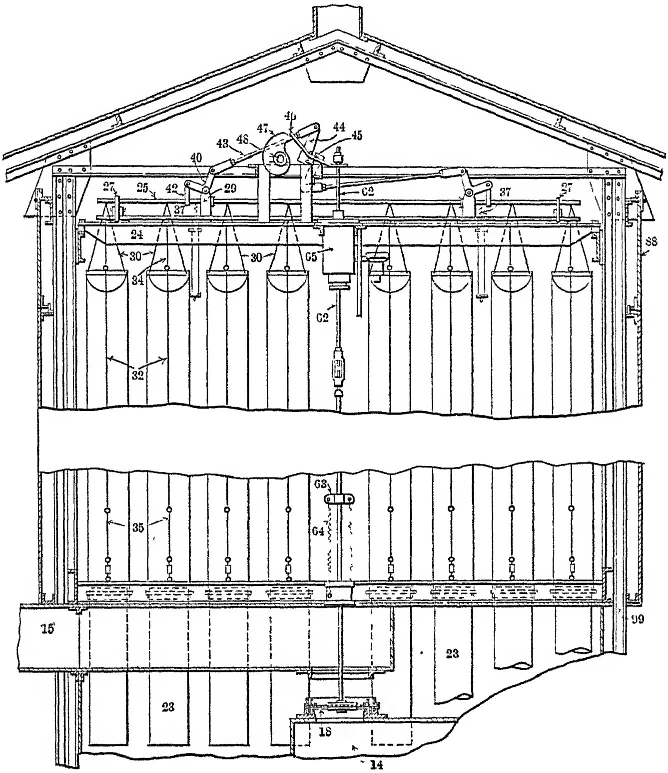

FIG. 5.

arms 44 are rigidly connected to the shaft 45, so that the cam acting against this striking plate causes shaft 45 to rock. This action is translated into a vertical snapping motion on the horizontal rod 25, through levers and rods 42, 40, 43, and 44.

Attention should here be called to the contact between striking plate 46 and rod 62. This is accomplished by slotting plate 46, so that when rod 62 has reached its top position, the plate 46 is no longer engaged with the rod 62 and may be freely actuated by cam 47. Two rods 32 are hung diametrically opposite at sides of each bag. Their lower ends are rigidly held on the thimble deck. The upper ends are attached to the

toggle arms 27 and are long enough to allow the ends of the toggle arms 27 their full travel.

The opposite ends of toggle arms 27 are slotted to receive the horizontal rod 25, the arms 27 being pivoted at their centers and held in position by the bearing 28. As the rod 25 has a vertical snapping motion, this motion is still further translated to the rods 32 through

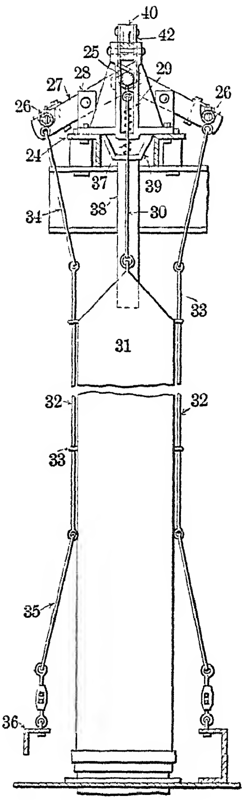

Fig. 6.

arms 27, so that these rods are first slackened and then suddenly thrown under tension, which gives them a decided whipping motion. As the bags are fastened to these ends by means of connections 33, this whipping of the rods causes a very close approximation to hand shaking on the bags.

It will be seen from the foregoing that during the shaking period the bags are under suction, and it has been found that the combination of suction and shaking very effectually cleans the bag fabric.

The removal of solids caught in hoppers is effected by screw conveyors.

Fig. 7 shows some pressure characteristics under varying conditions.

No. 1 with a ratio of 1.0 cu. ft. of gas per min. to 1 sq. ft. filtering surface.
No. 2 with a ratio of 1.5 cu. ft. of gas per min. to 1 sq. ft. filtering surface.
No. 3 with a ratio of 1.6 cu. ft. of gas per min. to 1 sq. ft. filtering surface.

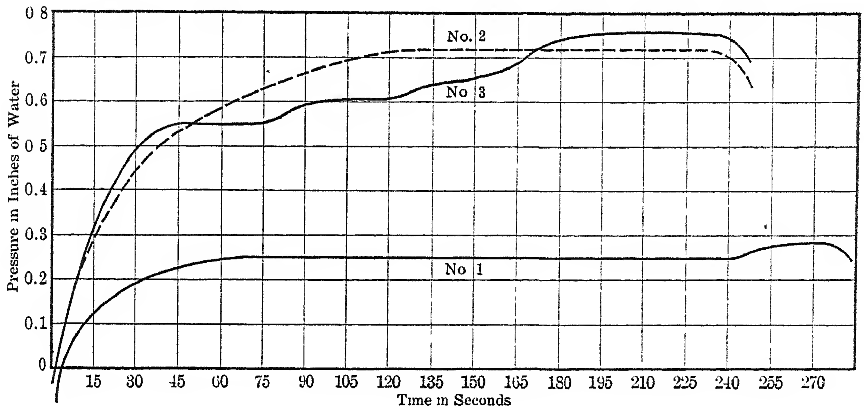

FIG. 7.—CURVES SHOWING PRESSURE IN BAGS BETWEEN SHAKING PERIODS.

The quantity of solids per cubic foot of gas was constant. Of course, with a decrease in the amount of these solids, the total bag pressure will drop.

Fig. 8 shows pressure taken simultaneously in the feed trunk, con-

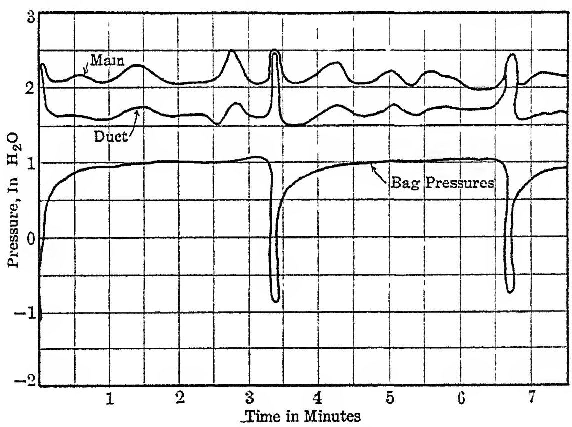

FIG. 8.—BAG HOUSE TEST. BAG HOUSE No. 3, CELL No. 1. FAN R. P. M. 325.

necting duct and at the bags, on one cell. At the time of suction, the duct and trunk pressures are equalized.

Depending upon the amount and character of solids to be removed, these houses filter from 1.5 to 4 cu. ft. per square foot of fabric area; or, roughly, about three times what can be expected on similar gas with stationary houses.

Aiming at a reduction of frictional resistance when handling large volumes of gas, alterations in design have been proposed by L. G. Rowand, of the New Jersey Zinc Co. At low velocities these losses are not serious.

The recent advent of suction filters from abroad into similar service allows some comparisons to be made. We believe that the pressure form of house offers certain advantages.

1. By dilution of filtered gas with any amount of cool air desired, hotter gas may be handled with little damage to the fabric. The stack effect of the individual unit can be made as great as desired. These houses, however, have a temperature limit of about 180° C.

2. Greater accessibility to bags and house mechanism whereby any small leaks may be detected with a minimum of time.

With the ability to close off independent cells when necessary, the bag-house man need enter only when the house has been freed of gas by a period of suction.

The power consumption of the shaking mechanism is approximately 2 hp. That required to move the gases through the house varies with filtering ratio, *i.e.*, cubic feet of gas to filtering surface and the amount of solids per cubic foot. Roughly, these limits have been from 1 to 1½ hp. per 1000 cu. ft. per minute.

Much credit is due Messrs. R. B. Hoffmann and F. J. Ford for the excellence of the mechanical and electrical construction.

Some Practical Hints in Bucket-elevator Operation

BY A. M. NICHOLAS, BRISBANE, QUEENSLAND, AUSTRALIA

(New York Meeting, February, 1918)

Preventing Settling during Elevation

When attempting to lift mill pulp containing a considerable percentage of wolframite, in an ordinary bucket elevator, difficulty was encountered from the tendency of the tungsten minerals to settle, on account of their high specific gravity. Lifts not exceeding 20 ft. (6 m.) could be accomplished without particular difficulty, because there was insufficient time for consolidation of the heavy minerals in the bottom of the bucket; but with higher lifts, the heavy tungsten minerals would settle so solidly that when the bucket turned over at the top of the elevator the contents could be only partially dumped. In this case it was necessary to lift the material a distance of 34 ft. (10 m.); hence some means had to be adopted to prevent settling, at least to such an extent that the material could be dumped from the buckets. To reduce the carrying time to a sufficient extent would have required a belt speed of 475 ft. (144.7 m.) per minute, which was not feasible.

It was decided to try, by vibrating the belt about midway of its span, to keep the material sufficiently agitated during elevation to prevent settling. Underneath the rising side of the belt was placed a 12-in. (30.48-cm.) idler pulley, 18 ft. (5.5 m.) up in the total lift of 34 ft. The idler pulley was set eccentric by ¾ in. (19 mm.) and it was hoped that the vibration thus imparted to the belt, running at a speed of 280 ft. (85 m.) per minute, would prevent settling in the buckets. It was found that the pressure of the belt on the idler, due to the small inclination of the elevator, was not sufficient to overcome sliding on the idler, and the agitation was insufficient to accomplish the desired purpose. The idler was then connected to the drive shaft of the elevator through an intermediate pulley, gearing down to a speed of 20 r.p.m., so that a positive vibration was imparted to the belt; this imparted enough motion to the belt to prevent settling and the contents of buckets dumped satisfactorily.

Protecting Elevator Belts

When elevating, from the crusher, a rock which was very sharp and abrasive, considerable difficulty arose from cutting of the belt under-

neath the buckets. As the bucket passed over the top pulley and dumped its contents, some of the fine particles of rock would slide down the belt and lodge underneath the bottom edge of the bucket ahead. The subsequent passing of the bucket over the pulleys would grind these fine, sharp particles of rock into the belt and cut it away so rapidly that its average life was only a few months. This trouble was overcome in the following manner.

Triangular prisms of wood, 2 by 2 in. (50.8 by 50.8 mm.) on the sides and as long as the belt was wide, were fastened with 1⅛-in. wood screws to the belt, one below each bucket, one leg of the triangle going next to the belt and the other leg going next to the bottom of the bucket. Thus, when the bucket was inverted at the top of the elevator, the wooden triangle acted as a shield over the crack between the bottom of the bucket and the belt, the hypotenuse of the triangle serving to divert the sliding particles of rock from the surface of the belt and thus preventing them from getting between the bottom of the bucket and the belt. At the cost of a few dollars, the life of the belt was increased several hundred per cent. A balata belt treated in this way has been in use for about 2 years, has hoisted approximately 50,000 tons of rock, and to all appearances is still good for at least another year of wear.

High-speed Belts

With narrow belts running at high speed, difficulty is often met in preventing slippage of the belt, due to a cushion of air between the pulley surface and the belt. For work of this kind, leather chain belt should be used. This belt is made of small blocks of leather overlapping at the ends and pinned together by a metal pin run through from one side of the belt to the other. This type of belt is in frequent use on wide pulleys, but its use on narrow pulleys at high speeds is not common. The metal pins keep the belt rigid from side to side, not allowing it to accommodate itself to the camber of the pulleys, but in a very short time it will wear down in the center to fit the camber, and then will give an excellent grip.

Small Pulleys for Large

With elevator and conveyor belts 14 in. wide (35.5 cm.), it is common practice to install three 4-in. pulleys side by side on the shaft, instead of a single 14-in. pulley, the three small pulleys being cheaper to install and maintain than a single large one.

Recent Tests of Ball-mill Crushing

BY C. T. VAN WINKLE, PH. B., SALT LAKE CITY, UTAH

(New York Meeting, February, 1918)

UNTIL the advent of the porphyry coppers and the introduction of flotation which soon followed, crushing and grinding for many years proceeded along somewhat stereotyped lines, without important alteration in type of machinery. For the finer crushing and grinding, stamps, rolls, and various patterns of Huntington and Chilean mills were in general use. Ball-mills were in use abroad, but owing to their small capacity and the high cost of screens and steel, they never obtained much footing in the United States.

Tube-mills were first introduced into the crushing departments of cyanide plants when it was found that for crushing finer than 30-mesh other types of crushing machinery were not efficient. In order to crush with one pass, these mills were made 18 to 22 ft. (5.5 to 6.7 m.) in length. Pebbles were used as a grinding medium and the mills were lined with either silex blocks or fragments of quartz or flint pebbles set in cement. While the cylindrical tube pebble-mill had been used to some extent in small installations of concentration mills, the first instance of its use on a large scale was at the concentrating plant of the Miami Copper Co., where 8-ft. by 22-in. (2.5-m. by 55.9-cm.) Hardinge mills were tried out against Chileans. The results of these experiments led to the gradual replacement of the Chilean by the Hardinge mill. Robert Franke published an article[1] describing the work done, comparing the two types of mills. At the same time, according to Franke, a test was run using a 6-ft. (1.8-m.) Hardinge ball-mill as a substitute for rolls for intermediate crushing on ½-in. material. According to Franke, this mill was soon discarded, since it was found that to obtain the desired product the mill must be limited in capacity. The Miami Copper Co. made no test with other types of ball- or pebble-mills. Following this example, others installed the conical type; and when the Inspiration Consolidated Copper Co. decided to build a concentrator, it adopted the conical mill. As the requirements for mills would be very large, it purchased manufacturing rights in the State of Arizona from the

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[1] *Trans.* (1913), **47**, 50.

Hardinge company, believing it would be cheaper to do this than to pay the manufacturer's profit.

In the spring of 1914, the Inspiration company built a 500-ton test plant to work out the final details of the grinding and flotation problem, its previous tests having already indicated the advantage of flotation. The regrinding mills in this 500-ton test plant consisted of 10-ft. by 28-in., 8-ft. by 36-in., 8-ft. by 44-in., 8-ft. by 72-in. Hardinge mills and a 6 by 20-ft. Chalmers & Williams tube-mill. These mills were equipped with pebbles as a grinding medium. During the operation of this test plant, the concentrator building was erected, of the same size and dimensions as that of the Miami Copper Co., having an estimated capacity of 7500 to 10,000 tons per day.

The general results of the regrinding mills at the Inspiration test plant showed that the 10-ft. (3-m.) Hardinge mill was the most unsatisfactory of all, due to the excessive pebble consumption and the power required to operate it. The mill of this type that gave the best results was the one that approached the cylindrical shape, having a cylindrical portion 72 in. in length (182.9 cm.). The mill that seemed to give equal results, as to power and pebble consumption, was the Chalmers & Williams tube-mill, although it required considerably more space than the 8-ft. by 72-in. Hardinge.

Introduction of Marcy Mill at Inspiraton

In August, 1914, the company installed a Marcy ball-mill 8 ft. (2.5 m.) in diameter and 5 ft. (1.5 m.) in length. This mill was experimental, an entirely new design, being the first mill in which the entire discharge end was fitted with a grizzly or screen. This grate was intended to deliver a maximum size of 1/8-in., and between the grate and the discharge end were lifters to discharge the undersize from the mill. It was claimed that by keeping a minimum of undersize in the mill the relative weight and efficiency of the balls was considerably increased.

By allowing the Marcy mill to take 3-in. feed and discharge a product below 1/8-in., capacity of the Hardinge pebble-mill was greatly increased and the general extraction was improved; it was found that an installation of Marcy mills followed by conical pebble-mills could readily treat 10,000 tons per day. As a result of the test in October, the company made arrangements to manufacture its own Marcy mills from the designs of the one that was in operation, modified by the results of their own experience.

At this time, it was suggested that it might be possible to do all the crushing in a Marcy mill arranged in closed circuit with a mechanical classifier; that is, to take the 3-in. feed and crush it to flotation size in one operation. During November and December, 1914, experiments with the Marcy mill and a new classifier were conducted, but were not

altogether satisfactory. In December, at the suggestion of Mr. Hardinge, the conical mills equipped with steel balls were tried in a similar manner, but with inferior results. By the first of 1915, since the Marcy mill had demonstrated that it could do the work in one operation, it was purchased by the Inspiration company and manufacturing proceeded.

The new concentration plant was started in July, 1915, equipped entirely with No. 86 Marcy mills, 8 ft. in diameter and 6 ft. in length, in closed circuit with Dorr classifiers, the product going to flotation machines and the sands from these machines to concentration tables. On starting, the shells of the Marcy mills were found to be defective, due partly to the light design and partly to the fact that the manufacturer did not have time under his contract to make and anneal the castings properly.

Test of Hardinge vs. Marcy Mill at Inspiration

Early in 1916, the Inspiration company decided to add two sections to its mill, and an offer by Mr. Hardinge to equip a section with two of his mills without cost to the company was accepted. These mills were expected to do the work of the same number of Marcy mills, with much less power. The fact that a joint test between Hardinge and Marcy mills was to be run by the Inspiration company was widely advertised and created considerable interest among those interested in crushing; since the expense of crushing is greater than that of any other milling operation, these tests were of considerable importance. A statement by David Cole[2] covers this very well and is therefore repeated verbatim:

> The comparison of work done, based upon the scientific theory of Stadler, Gates, Kick, *et al.*, is beautiful on paper, but there are a lot of us who hesitate to accept the theory as "law." We are inclined to regard a direct comparison of grinders arranged side by side, getting feed from a common source through a mechanical distributor, and making a product that affords as nearly as may be the same screen measure, and at any rate affording an equal metallurgical opportunity for the subsequent treatment, as the Supreme Court in these grinding matters. The Marcy versus Hardinge ball-mill controversy is soon to have this kind of a hearing at the Inspiration plant, and the results will be watched with great interest.

As no data have yet been given out regarding this test, I have thought this a good opportunity to publish the facts.

This test was begun April 4, 1917. A section comprising two 8-ft. Marcy mills equipped with 225-hp. motors, which had been in continuous operation since January, 1917, was used in comparison with a section comprising two 8-ft. Hardinge mills equipped with 150-hp. motors. Each of the Marcy mills took the coarse feed from the bin and, in closed circuit with a 6-ft. Dorr classifier, made a finished product.

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[2] *Trans.* (1916), **55**, 705.

The Hardinge mills were first arranged in tandem, the first mill taking all of the coarse feed from the bin, its product going to a Dorr classifier, the sands from which passed to the second Hardinge mill working in closed circuit with the second Dorr classifier. Each of the sections was equipped with an automatic scale so that the total or the hourly tonnage could be recorded and noted. The crushed product, the overflow from the Dorr classifiers, was carefully sampled in each case by automatic samplers. The daily report sheets of the finished product showed some variation from the desired 2 per cent. on 48-mesh with both types of mills, but by applying a correction factor the final results, as tabulated, could be reduced to the basis of 2 per cent. on 48-mesh. This correction factor was derived by Dr. Gahl from actual operating experience. The results are as shown in Tables 1 and 2.

TABLE 1.—*Screen Analysis of Feed to Ball-mills*

	Per Cent.	Cum Per Cent.
On 1.5-in.	17.7	17.7
On 1-in.	16.5	34.2
On ⅜-in.	24.7	58.9
On 3-mesh	7.3	66 2
On 6-mesh	7 7	73 9
On 8-mesh	2 2	76.1
On 14-mesh	4.8	80.9
On 28-mesh	3.6	84.5
On 48-mesh	2.9	87.4
On 100-mesh	2.3	89.7
On 200-mesh	1.5	91.2
Through 200-mesh	8 8	100.0
	100 0	

The daily reports show that various ball charges and various sizes of balls were used in the Hardinge mills; that the speed of the Hardinge was changed a number of times; various types of scoop feeders were used; the delays due to overloading the Hardinge mill, changing balls, etc., as mentioned, were very great. The Marcy mill continued with its ball load unchanged and practically without delays.

The record shows that the capacity of the Marcy mill was 130.5 per cent. greater than the Hardinge, and the Marcy saving in power over the Hardinge was 34.04 per cent. At times the motors of both types of mills were slightly overloaded. As the power was measured by integrating wattmeters, this does not affect the results and comparisons given.

On May 15, Mr. Hardinge said he wished to experiment with his mills so as to do better work. The results show, however, that he did not increase his capacity nor decrease his kilowatt-hours per ton. The

Table 2.—*Operating Details of Competition between Marcy and Hardinge Mills*

Marcy Section	Hardinge Section
Duplicate mills, 8 ft. by 72 in.	Duplicate mills, 8 ft. by 36 in.
Spiral scoop feeders	Spiral scoop feeders on both primary and secondary mill.
Lining, Mn steel, Krupp type	
Grates, Cr steel, ¼-in. openings	Lining, Cr steel.
Speed, 24 r.p.m.	Speed, 26 r.p.m.
Motors, 225-hp.	Motors, 150-hp.
Cr-steel balls of following sizes:	Cr-steel balls of following sizes:

Marcy		Hardinge Primary		Hardinge Secondary	
2¼ in.	1,880 lb.	5 in.	13,000 lb.	2 in.	14,500 lb.
2½–3 in.	7,290 lb.	4 in.	10,500 lb.	1½ in.	10,500 lb.
3½–3 in.	15,445 lb.	3 in.	8,500 lb.	1 in.	7,000 lb.
3½–4 in.	5,275 lb.				
	29,890 lb.		32,000 lb.		32,000 lb.

Marcy Section	Hardinge Section
Weight of each mill (empty) and motor, 85,000 lb.	Weight of each mill (empty) and motor, 40,000 lb.
Duplicate Dorr classifiers, 6 ft. by 26 ft. 7¾ in.	Duplicate Dorr classifiers, 6 ft. by 26 ft. 7¾ in.

	Two Marcy	Two Hardinge
Daily tonnage (dry), corrected to 2 per cent. on 48-mesh..	1118	485
Kw.-hr. per ton crushed..............................	8.52	11.42

Hardinge mill results from May 15 to June 11, when the contest ended, were not so good as shown in the data given. The figures showing daily tonnage and kilowatt-hours per ton are averaged from the daily report sheets issued by the Inspiration management. These figures were accepted by the manufacturers of both the Hardinge and the Marcy mill, and there is no doubt as to their correctness.

No ball consumption was given out by the Inspiration company on the Hardinge mills because many changes had been made in the ball load. The operation of the Marcy mills was in charge of the regular mill crew, while that of the Hardinge section was under the supervision of Mr. Hardinge and his assistants, who were at the plant from April 4 to June 11, when the test was discontinued. The ball consumption of the Marcy mill in the entire plant is 1.7 lb. of steel for each ton of ore crushed. The speed of the Hardinge mills was faster than the Marcys; the ball load was greater, and from the tabulated reports, the tonnage was less than one-half. From this, it would appear that the ball consumption in the Hardinge mill would be nearly double, as the total daily ball consumption depends upon the speed and number of balls used in the mill rather than upon the amount of ore crushed.

The ball-mill floor in this plant is equipped with a traveling crane capable of picking up a mill and its load of balls. When a mill needs

relining, the bearing caps are removed, the mill is picked up by the crane, and a relined mill with its load of balls is placed in the same bearings. This saves the time that would be lost if the mills were lined in place, so that the actual loss of time due to ball-mills in the entire Inspiration plant averages less than 0.4 per cent.

Fine Crushing at Anaconda and Lake Linden

The Anaconda Copper Mining Co. purchased about 50 Hardinge mills in January, 1915, when it decided to install flotation. The mills were 10 ft. (3 m.) in diameter with a 60° cone on the feed end and a 40° cone on the discharge end, and with the cylindrical portion 48 in. (121.9 cm.) in length. This was about the size of one of the Hardinge mills used in the Inspiration plant and, as heretofore pointed out, was the most undesirable.

The Anaconda mills were equipped with 225-hp. motors, so that balls could be used. It was found that the pebble consumption was from 12 to 15 lb., which was prohibitive, and when steel balls were used the motors were not of sufficient capacity, for which reason, it was necessary to lag up the mills with wooden blocks. The cylindrical portion is now 7 ft. 6 in. (2.29 m.) in diameter, and about the same length, and the mills, due to the 40° discharge end, are practically cylindrical mills. The fifty 10-ft. Hardinge mills of the original installation have all been rebuilt to the above size and are operated at 15 r.p.m. The effect of converting these into cylindrical mills and reducing the speed has been a great improvement in cost and character of operation, as compared with the original recommendations.

The Calumet & Hecla Co. has installed sixty-four 8-ft. by 16-in. (2.44-m. by 40.64-cm.) Hardinge mills in its crushing plant at Lake Linden. These mills use pebbles and crush about 45 tons per day each, taking feed at below 3/16 in. and reducing it to about 30-mesh. A new crushing plant of this company, however, will consist of 8-ft. mills having a cylindrical portion 72 in. in length, which will make their inside dimensions practically the same as those of the Anaconda Copper Mining Co. The Calumet & Hecla Co., in running a test with a 5 by 20-ft. (1.5 by 6-m.) tube-mill and a Hardinge mill, found the tube-mill equally efficient, but it required too much space.

Arthur O. Gates, of Purdue University, said:[3]

> Analyzing the mill on the assumption that the greatest diameter is to produce the greatest effect in crushing, we find that the weight of crushing pebbles is proportional to the square of the diameter (machine half full); that the energy per unit pebble weight is something nearer the square than the first power of the diameter; and that the velocity with which the ore or pulp being crushed passes through the mill is inversely proportional to the square of the diameter. The result is that the energy applied per pound of pulp at various points along the cone is inversely proportional to

[3] Discussion of paper by Robert Franke, *Trans.* (1913), **47**, 58.

about the sixth power of the diameter. This means that half way toward the apex of the cone, only $\frac{1}{64}$ as much work is done as at the cylindrical portion, while three-fourths of the way toward the apex, only $\frac{1}{4000}$ is done.

At Anaconda, and at the Calumet & Hecla mill, it has been found that a lengthening of the cylindrical portion increases the efficiency and capacity of the Hardinge mill. Undoubtedly, in the Hardinge mill there is a tendency for the smaller balls and pebbles to segregate in the conical portion. Taggart has shown,[4] however, that the segregation decreases the efficiency of the mill. He says:

> A ball charge composed of 5-in. balls makes a greater reduction in the size of particle at one passage through the mill than a mixed charge composed of 5-in., 4-in. and 3-in. balls.

The reason for the greater reduction in the size of the particles is that the smaller balls tend to segregate in the conical portion of the mill and cut down its efficiency, both on account of the small size of the cone and the small size of the balls themselves. There is not sufficient energy to do the work.

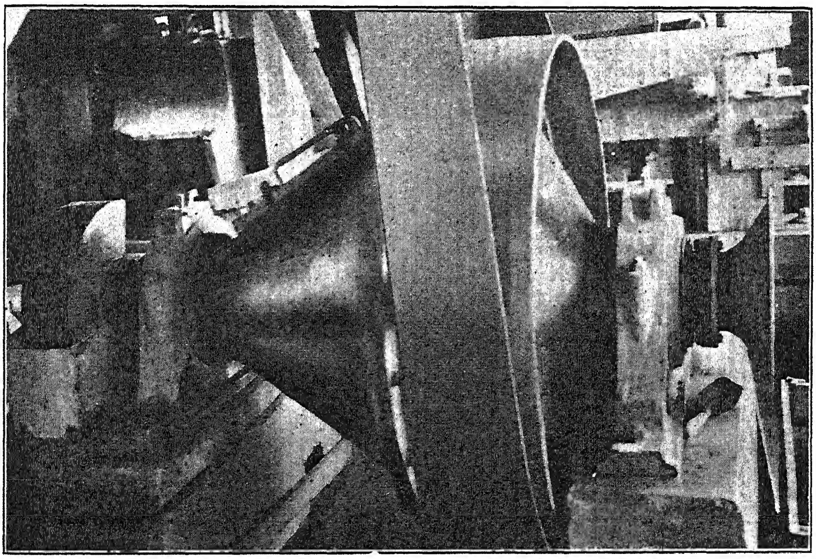

Fig. 1.—Mounting laboratory Hardinge mill for reversed feed.

Reversing Feed to Hardinge Mill

In January, 1917, I carried on experiments with the Hardinge mill in the laboratory of the General Engineering Co., to determine its efficiency. It would appear that if the feed were introduced into the so-called discharge end there would be a marked difference between

[4] A. F. Taggart: Tests on the Hardinge Conical Mill. *Trans.* (1918), **58**, 126.

the resulting product and that produced when the feed is put into the mill through the feed end, in the regular way. To conduct this simple experiment, I operated a 36-in. (91.44-cm.) Hardinge pebble-mill, feeding first in the regular way, into the short cone. After running this test, I placed the scoop feeder on the long, or discharge end, and ran a second test in this manner. The entire product in each case was caught in a tank, then mixed and sampled. My tests were carefully run on samples of quartz gravel, using about 1 ton of gravel to each test, with particular care to maintain uniformity of operating conditions for both tests. These samples, both feed and discharge, were carefully mixed and a portion cut out for screen analysis. All slimes were first washed out of the samples to be screened, through a 200-mesh sieve, and dried and weighed. The sands were then sized on Tyler standard sieves, using a Rotap machine, with results shown in Table 3.

TABLE 3.—*Screen Analysis of Feed and Products of Hardinge Mill*

Product on Mesh	Feed		Regular Way, Product Discharged from 30° Cone		Reverse Way, Product Discharged from 60° Cone	
	Per Cent.	Cum. Per Cent.	Per Cent.	Cum. Per Cent	Per Cent	Cum. Per Cent
4	3.2	3.2				
6	11 7	14.9				
8	15.5	30 4				
10	17.1	47.5				
14	13.4	60.9				
20	11.5	72.4				
28	9.5	81.9	5.2	5 2	5.2	5.2
35	5.0	86.9	7.2	12.4	7.0	12.2
48	5.5	92 4	12.6	25.	13.1	25 3
65	3.2	95.6	12.5	37.5	12.8	38.1
100	2.1	97.7	11.9	49.4	12.0	50 1
150	2.3	100.0	11.3	60 7	11.5	61 6
200	.....	.....	7.7	68 4	7.5	69.1
– 200	.....	.....	31.6	100.0	30.9	100.0
	100.0	.....	100.0	.....	100.0	

Two similar tests were made at the University of Utah, using a mill of the same diameter, 3 ft., but with a shorter cylindrical portion, which, therefore, did not crush so rapidly. The result of these two tests confirmed the data observed in the first test, except slightly greater reduction in average size when operated the reverse way. This work was checked and reviewed by Prof. Robert S. Lewis. The power instruments were connected to the motor by the electrical department for the purpose of ascertaining whether the motor requirements differed when the scoop feeder was changed from feed to discharge end. From

the averages, no differences could be determined. On account of the light motor load and heavy friction load, no attempt was made to determine the efficiency of the mill by measurement of power.

I will draw no conclusions from my own experiments, but desire only to say that I believe they are of sufficient importance to be repeated with a large conical mill. When operating a Hardinge mill at a very reduced tonnage, it is possible to make a fairly uniform product in one pass, just as it is with a cylindrical overflow mill with a reverse screw in the trunnion; but when operating with a large circulating load, according to modern practice, the shape of the conical mill is a disadvantage. It is suggested that the conical mill is strong because of its truss shape; but it seems unnecessary to build a truss over a long span when a tubular construction can do better work within less space and is equally strong. For instance, the conical mills at Inspiration were 16 in. longer between the bearings than the Marcys, with less than half the capacity.

The Marathon, or rod-mill, has not been adopted as quickly as one would expect. Undoubtedly it requires more care than a ball-mill, and its mechanical troubles offset its power efficiency in some degree. If the rods become bent its great advantage is lost. Its particular field is in fine crushing where slimes are considered undesirable.

DISCUSSION

John W. Bell,* Montreal, Canada (written discussion†).—Mr. Hardinge's "hammer" theory is, I believe, a sound one; but, unfortunately, at the very place in the Hardinge mill where there should be a large number of small "hammers," there is room for only a very few. The results in Mr. Van Winkle's paper seem to indicate that the practical development of the theory can best be accomplished by stage crushing, using cylindrical mills. It would be very interesting to know if any stage-crushing experiments have been made at Inspiration with Marcy mills.

Mr. H. Kenyon Burch says:[1] "The Marcy mill also proved to be a most excellent intermediate crusher, handling as high as 800 tons of 3-in. feed and under, to pass an 8-mesh screen without return of oversize."

It seems reasonable to suppose that a large part of this output would be a finished product; consequently, if it were possible to send the oversize from two of the primary mills to one secondary mill using balls of small diameter, a considerable saving in power might be realized, provided it were not necessary greatly to enlarge the secondary mill. It does not seem reasonable to suppose that fine material can be crushed

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* Assistant Professor of Mining Engineering, McGill University.

† Received Feb. 8, 1918.

[1] *Trans.* (1916), **55**, 725.

as quickly or as efficiently in a primary ball-mill as in a re-crushing mill especially designed for that work. Experimental data, of course, are essential in deciding questions of this kind.

In regard to Mr. David Cole's statement quoted by Mr. Van Winkle, that was made a long time ago and progress has been achieved since then. I eliminate the first sentence, because if Mr. Cole can find beauty in a controversy which was fought with words, and for the most part quite unsupported by experimental data, he is more of an optimist than I am. My quarrel is with only one of the judges in Mr. Cole's Supreme Court, and I suggest the recall for him. His name is "—48-mesh efficiency." The other two judges ("cost of operation" and the "effect of the character of the grinding on extraction") are wholly admirable, and a decision from them can be obtained only by the method Mr. Cole recommends.

Appreciating fully that the relative mechanical efficiency is only one of three very important considerations, it is none the less a weighty one, and should be determined with all the accuracy possible. While the −48-mesh method is a paragon of virtue compared with the Stadler-Kick method, I have not yet found a single reason for considering the −48-mesh superior to the Rittinger method; and there is an excellent reason for considering it decidedly inferior, namely, its failure to give proper credit to a crusher for the percentage of each grade in the crushed product. This defect is disclosed by Mr. Van Winkle. In the Inspiration tests, because the two machines under comparison failed to turn out an exactly similar product, it was necessary to apply a correction factor. It is desirable to know what facts can be marshalled in support of the continuation of this method in preference to the Rittinger method.

J. Parke Channing, New York, N. Y.—Mr. Van Winkle refers to the comparative tests of the Marcy and the Hardinge mill at the Inspiration concentrator last spring. I happened to be in Miami at that time and saw the mills in operation. The problem presented to the two manufacturers, Messrs. Marcy and Hardinge, was to install in a certain definite space, in one of the sections of the Inspiration mill, enough milling capacity to crush at least 1000 tons in 24 hr. It was just possible to fit into this area two Marcy mills or only two Hardinge mills. The staff of the Miami Copper Co., who were very much interested in Hardinge mills, thought that Mr. Hardinge was overconfident in attempting to crush 1000 tons a day with two of his mills in this floor space; with the knowledge that we had of his mills, we felt that this could not be accomplished with less than three mills. Mr. Hardinge, I understand, based his expectations on some work that he had done for the Nevada Consolidated, but we believed that the ore of the Nevada Consolidated was much softer than that of the Miami and the Inspiration. The operation of the Hardinge mills in this section was unsatisfactory, because of attempting to crowd altogether too much ore through these two mills.

The Miami Copper Co. had cast its lot with the Hardinge mills, and it is difficult, when you once determine on a particular type of machine, to change over to another. Our sections had originally been laid out each with a roll for the preliminary crushing, followed by two parallel Hardinge mills, in closed circuits, for the final crushing. From experiments we had made in previous years, and also from results of the work in our sections provided with two Hardinge mills, we concluded that in equipping the plant for increased capacity of 1000 tons per section it would be best to put in three Hardinge mills and eliminate the roll. This we did, notwithstanding the apparent unsatisfactory results at Inspiration, and in the latter part of 1917 the installation of these mills in section 6 was completed, and the first long run was in January, 1918, with satisfactory results.

B. Britton Gottsberger,* Miami, Ariz. (written discussion).—Reading Mr. Van Winkle's paper has reminded me that during the Arizona meeting, at the session on fine-grinding, held in Miami, I stated that the Miami Copper Co. was installing Hardinge ball-mills which would yield a product of the same fineness as was being obtained by the Marcy mills at the plant of the Inspiration company, so that a comparison of the methods of crushing and grinding ore used at the two plants might be made. Work on the changes in the Miami mill has for various reasons made slow progress, but last fall the first section completely equipped with ball-mills for fine-grinding went into operation, and it is now possible to give figures showing the results obtained. I have not sufficient information at hand to enable me to make a critical comparison of the work being done in the two plants, but wish to submit a concise statement of the latest methods used at Miami and the results obtained covering the crushing from mine rock to the point of reduction necessary for ore treatment.

The ore hoisted through the main shaft is dumped into a 1000-ton bin located at the head of the crusher plant. This plant consists of No. 7½ gyratory crushers followed by two sets of rolls 55 by 20 in. and 42 by 16 in., respectively, operating in closed circuit with trommels fitted with screens having ⅝ by 1⅛-in. slotted holes. Practically all of the product will pass a ¾-in. round hole, as shown by the average screen analysis for the month of January given in Table 1.

The product of the crusher plant is carried by belt conveyors to the mill bins, located back of each section of the plant, having a total capacity of about 10,000 tons. From this point reduction of the ore is carried out entirely in Hardinge ball-mills, three of these machines being installed in each section to handle approximately 1000 tons per day of crusher-plant product, which is ground to a point where practically nothing remains upon a 48-mesh screen. The mills are built of cast iron and are

* General Manager, Miami Copper Co.

8 ft. in diameter by 36 in. length of barrel, driven direct by electric motors through Wuest gears. Each mill is equipped with a 150-hp. motor and runs at 20.6 revolutions per minute.

TABLE 1.—*Screen Analysis of Feed to Ball-mills*

	Per Cent.	Cum. Per Cent.
On ¾-in. round hole...	1 1	1 1
On ½-in. round hole...	13 8	14 9
On ⅜-in. round hole...	13.7	28.6
On ¼-in. round hole....	12 2	40 8
On $\frac{3}{16}$-in. round hole...	7 4	48 2
On ⅛-in. round hole...	9.3	57.5
On 10-mesh....	8 3	65.8
On 14-mesh.	4 4	70 2
On 20-mesh..	3 3	73 5
On 28-mesh...	4.0	77.5
On 35-mesh..	2.4	79 9
On 48-mesh...	2 7	82 6
On 65-mesh..	2 0	84.6
On 100-mesh.	1.5	86.1
On 150-mesh...	1 9	88.0
On 200-mesh....	1 3	89.3
Through 200-mesh.	10 7	100.0
	100.0	

The crushing is at present done in two stages. The entire section tonnage is first subjected to single-pass crushing through one mill, the product passing to a 4½-ft. Dorr classifier. The overflow of the classifier is finished product. The sand product of the classifier, representing the oversize of the first mill, is divided equally between two mills of the same size, each operating in closed circuit with a 6-ft. Dorr classifier. The overflow of these classifiers is finished product, the sands being returned to the mills for regrinding. The character of the product of this system of crushing is shown by the average screen analysis of the tailing of section 6 of the plant for the month of January, 1918, given in Table 2.

TABLE 2.—*Screen Analysis of Hardinge Ball-mill Product*

	Per Cent.	Cum. Per Cent.
On 28-mesh...	0.0	0.0
On 35-mesh...	0.1	0.1
On 48-mesh...	0.4	0.5
On 65-mesh...	3.8	4.3
On 100-mesh...	14.2	18.5
On 150-mesh...	14.8	33.3
On 200-mesh...	6.3	39.6
Through 200-mesh...	60.4	100.0
	100.0	

The average tonnage handled in section 6 by the three mills during the month of January, 1918, was 987 tons per 24 hr. The power consumed in grinding by the three mills, according to wattmeter readings, amounted to 7475 kw.-hr. per day, equivalent to 7.57 kw.-hr. per ton. The power consumption for the preliminary reduction is very small. We have no accurate wattmeter readings on this, but according to our regular power distribution, figured from ammeter readings, the power for preliminary coarse crushing, conveying, and operation of the Dorr classifiers, amounts to 1 kw.-hr. per ton. Therefore, the total power consumption from mine rock to finished product is 8.57 kw.-hr. per ton.

H. W. Hardinge, New York, N. Y. (written discussion*).—Many of Mr. Van Winkle's statements are exaggerations, due no doubt to ignorance of the subject he has tried to handle at second-hand.

Many of Mr. Van Winkle's statements are, from my personal knowledge, misstatements, probably based on this second-hand misinformation.

Mr. Van Winkle has simply lent himself as a catspaw to extract the Marcy chestnuts from the metallurgical fire.

I must disclaim his right to impute to me statements and admissions, as he has done in his paper.

In the competitive test referred to by Mr. Van Winkle, no mention was made of the fact that both of the Marcy mills broke down and were out of commission during several days of the very period of which he writes.

E. H. Kennard,† Los Angeles, Cal. (written discussion‡).—I will confine my discussion of Mr. Van Winkle's paper to that part which treats of the test between the Hardinge and the Marcy mills at Inspiration. Mr. Van Winkle neglects to mention how he secured the data upon which his paper is based. The only statement published, so far as I have been able to learn, are the figures published by Mr. Marcy in his advertisement. I conducted the test for the Hardinge Conical Mill Co. and, although I am their representative in the Southwest, I feel it my privilege to reply to Mr. Van Winkle, even though the Inspiration management has not seen fit to give out the results of the test. The data, to be of benefit to the engineering profession, should cover all of the facts.

Mr. Van Winkle states that a section composed of two Marcy mills, which had been in continuous operation since January, 1917, was used for the comparison. I arrived at the Inspiration concentrator on Apr. 9, five days after the Hardinge mills had started. Mr. Marcy had been at the Inspiration shortly before to superintend the preparation of the two

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* Received Feb. 25, 1918.

† Of Kennard and Bierce, Mining and Metallurgical Engineers.

‡ Received Feb. 25, 1918.

mills he placed in section No. 13 to compete with the Hardinge. From information the Inspiration management had gained by careful study of his mills, he knew that a mill whose liners had been worn 3 or 4 months and whose grate openings were also worn, showed an increase in capacity equal to 15 to 20 per cent. Mr. Van Winkle's statement that the Marcy mills had been in continuous operation since January is probably a fact, but he neglects to furnish the valuable part of that information, namely, the life of liners at the high point of efficiency. In this case, one mill went completely to pieces, liners, grates and all, on May 22, and the other one on June 3, which gave a total life of 5 months from the time they were installed, and a life of 6 weeks to 2 months after being placed in competition with the Hardinge. The breast liners of a No. 86 Marcy mill consist of 16 pieces, each weighing 1300 lb., a total of 20,800 lb.; the head liner, in one piece, weighs 6000 lb., the grates, which are fabricated on the ground from leaves cast in the east, weigh 3250 lb. That makes 30,000 lb. of manganese steel consumed in 5 months.

All sections throughout the Inspiration concentrator have two mills, marked A and B, each mill having its own watt-hour meter. I read the meters on the special Marcy mills every day for 2 months and my notes show that the B mill used more power than the A mill. Mr. Van Winkle mentions that the motors of both types of mill were slightly overloaded at times. The motor driving each of these mills was of 225 hp.; the input to the motor on the A mill was 240 to 250 hp., and to that on the B mill 255 to 270 hp. The Hardinge mills required different horsepowers even when each mill was carrying a load of 32,000 lb. of balls. Ball loads were varied from 24,000 lb. to as high as 42,000 lb. The most efficient point for the 8 ft. by 36 in. mill appeared to be between 28,000 lb. and 30,000 lb. of 2½-, 3-, 4-, and 5-in. balls. Referring to Table 2 of Mr. Van Winkle's paper, it will be noted that the primary Hardinge mill, which was the A mill, had a charge of 5-, 4-, and 3-in. balls, while the secondary, or B, mill had a charge of 2-, 1½-, and 1-in. balls. The wattmeter readings for these loads showed the A mill to be drawing 140 hp. and the B mill 150 to 155 hp. I attribute the difference to the fact that in the mill with the larger balls there was a rolling action, whereas in the B mill the load was more compact, presented greater friction, and was more of a direct lift with little rolling. There is a great difference, however, between an overload of 155 hp. on a 150-hp. motor and an overload of 270 hp. on a 225-hp. motor.

As was to be expected with new mills, it was necessary to make changes in pulp consistency, speed of mills, and ball load to determine the most efficient point of operation. Mr. Van Winkle mentions that the Marcy mill was in charge of the regular mill crew while the Hardinge section was under the supervision of Mr. Hardinge, the inference being that Mr. Marcy took the worst of it by not being present. He does not recite the

facts that this crew operating the Marcy mills had been trained for 2 years, that during the first year in which the Inspiration operated the Marcy mills their average was around 375 tons per mill, and that it had been by the most diligent work and close observation that the efficient management of this wonderful milling plant was able to raise the tonnage in the Marcy mills to nearly 500 tons per day. The fact that experienced mill operators are required to keep the tonnage of the Marcy mills at a maximum is further exemplified by the circumstances that in October, 1917, after the strike at the Inspiration company's concentrator, new operators, not experienced with the Marcy mills, were able to obtain a tonnage of only about 750 tons per 24 hr. for each section of two mills, this being the same tonnage as was obtained during the first year's operation of the Marcy mills in this plant. This indicates that it is the high-priced mill man ($5.75 per 8-hr. day) and not the machine that should be given credit for excess efficiency.

The Marcy mill, while ponderous and large, is nevertheless a delicate piece of machinery to operate at its highest efficiency. One operator can handle only two sections. In addition, there is a man on each shift, called the floor-walker, who is an expert on the peculiarities of the Marcy mill, whose only duty is to walk up and down the aisle watching the Marcy mills and ready to render assistance when something happens. There is also the shift-boss, who devotes nearly all of his time to the Marcy mills. The operator has no other duty and it requires his constant attention. I have seen operators leave their positions for 10 or 15 minutes, when a change of feed or water going into the mill would almost instantly cause the mill to choke or give the classifier an overload which would require the assistance of the ball-mill gang, floor-walker, shift-bosses and everybody available to get the section in operation again. An overload is indicated by the ammeter reading, which the operator keeps his eye on at all times.

Table 2, purporting to be the details and the results of the test between the Marcy and Hardinge mills, is misleading because Mr. Van Winkle does not state that this report represents only one particular day, and is not an average nor anything like it. It gives no details of time lost nor the causes for the low tonnage recorded. Between April 5 and May 15, each morning Dr. Gahl gave the Hardinge company, and mailed Mr. Marcy, the results of the preceding day. Mr. Van Winkle's Table 2 is a copy of the form used.

There were many delays in the Hardinge section due to overflowing of the launders and other causes, aside from trouble with the mills. At times they would be running for periods of half an hour to an hour without feed, but the meters would register a power consumption all the while. Mr. Van Winkle has explained that the Hardinge mills were first arranged tandem; that is, the A mill was taking all of the coarse feed with

no return of oversize, while the B mill was finishing the product from the A mill, working in closed circuit with a classifier. By this arrangement, both classifiers were headed in the same direction, whereas the classifiers in the other sections were working in opposite directions. This brought the overflow of both classifiers in the Hardinge section to the feed end of the A mill, which made the launder from the B mill the full length of the mill and classifier, about 45 ft. The drop in this launder was insufficient to carry the pulp, and a great deal of difficulty was experienced. As the management anticipated trouble from this source, an air-lift had been devised to elevate the pulp about 3 ft. above the discharge lip of the mill, but as sufficient air was not always available, a gravity flow became necessary. This was the cause of much lost time.

The correction factor devised by Dr. Gahl, to which Mr. Van Winkle refers, was worked out to penalize the ball-mill operators who were trying for high tonnage at the expense of the flotation department. The required fineness was 2 per cent. on 48-mesh. An arbitrary deduction of 15 tons was taken from the finished tonnage for each per cent. in excess of 2 per cent. If a Marcy section finished 1000 tons with 3 per cent on 48-mesh, 15 tons were deducted. If a Hardinge section, operating a part of the day, finished only 500 tons with 3 per cent. on 48, a deduction of 15 tons was made. In one case the deduction was 1.5 per cent. and in the other 3 per cent. Dr. Gahl recognized this point and informed me that his rule was not applicable unless the tonnage of all sections was equal. Due to the launder difficulties, which necessitated the use of excess water, it was difficult to regulate the classifier overflow, so that we often delivered high oversizes for short periods. If the sample was cut during one of these periods our day's record would show up very poorly, and by applying the correction factor we would suffer a heavy penalty. A specific case will make my point clear. The afternoon shift of May 16 finished 225 tons to 1.2 per cent. on 48-mesh; the graveyard shift finished 171 tons with 11.4 per cent. oversize; we were therefore penalized 141 tons, leaving but 30 tons credited in an 8-hr. shift to two mills. Dr. Gahl immediately saw the injustice of such records and no further reports were issued. This may account for the statement by Mr. Van Winkle that the Hardinge results from May 15 to June 11 were not so good as shown in the table. He has no actual record to show whether they were as good, better, or worse. He says that on May 15 Mr. Hardinge wished to experiment with his mills; the change referred to was made between April 30 and May 4, when the classifier was turned so as to allow each mill to work in closed circuit.

Mr. Van Winkle states that the Marcy mill continued with its ball load unchanged and practically without delays. This can be readily understood from the fact, cited above, that Mr. Marcy had the benefit of 2 years' practical operation, and he knew, before the test began, just

what was required for the highest record in a short test. Mr. Van Winkle states the lost time for the entire plant as 0.4 per cent. not mentioning what it was for the special section upon which his paper is based. Sixteen days required to put a mill in repair, which had been in a test only 48 days, to a disinterested mathematician, looks like 33 per cent. lost time.

Regarding the delays, and the time required to change linings of the Marcy mills, it is true that the Inspiration concentrator is so equipped that the entire Marcy mill, weighing, with its ball load, 110,000 lb., can be moved and a new mill placed in the same bearings in a short time; but in order to do this it required a 60-ton crane and six extra Marcy mills in reserve at all times. It happened, during the time I was at Inspiration, that the 60-ton crane was out of commission for a period of about 2 weeks, when the 40-ton crane had to be used. This required the ball load to be dumped from the mill before moving it from its bearings, and necessitated a gang of eight men and 5 hr. time. As I have mentioned, the grates and liners in these special Marcy mills went to pieces May 27 and June 3, and it was not until June 9 that they were relined and new grates were placed so they could be returned to their bearings and finish the race. During the time these mills were out for repairs, the repair gang of five or six men worked continuously, two shifts per day, in order to get these two mills into operation again before the Hardinge mills were withdrawn.

Mr. Hardinge had concluded some time before that the mills he had installed did not fit into the scheme of crushing required by the conditions in this plant, and had signified to Dr. Gahl his willingness to terminate the test. When Mr. Marcy learned that the Hardinge mills were to be taken out he made an appeal that we continue until his mills could get back into the race. It was agreed that we would remain until the Marcy mills could be prepared for a new start, and after taking the figures for one day's run of 24 hr. we would quit. The first 10 hr. of that last run the Hardinge mills finished their ore to the required degree of fineness with the expenditure of 8.55 kw.-hr. per ton, but 2 hr. was then lost by the breaking of the rocker arm on the classifier; following this were other delays caused by launders overflowing, etc.; so the final day furnished no really reliable data as to the merits of the two mills.

Albert E. Wiggin,* Anaconda, Mont. (written discussion†).—I would like to make a few remarks and criticisms in connection with what Mr. Van Winkle says about fine-crushing at Anaconda.

First, concerning our adoption of the 10-ft. diameter by 4-ft. cylinder Hardinge mill, which particular size Mr. Van Winkle states was found to

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† Received Feb. 25, 1918.

be the least desirable of the various Hardinge mills tested at the Inspiration plant: we tested a Hardinge pebble-mill of this particular size against an 8 by 12-ft. Power and Mining Machinery Co. tube-mill, using pebbles, and having a trunnion discharge. The following results of this test showed the Hardinge mill to be slightly superior to the tube-mill.

	Hardinge Mill	Tube-mill
Tons crushed per 24 hr.	163 0	176 9
Horsepower per ton crushed	0 69	0 74
Pebbles consumed, lb. per ton crushed	7 2	14 0
Kind of pebbles used	Danish	Danish and French

The mills were installed and the tests were conducted as recommended by the respective companies. The feed consisted of sand tailing all finer than 2 mm. and containing practically no slime. The mills were operated in closed circuit with a Dorr classifier. In connection with the pebble consumption shown above, it should be noted that while the Hardinge test was being conducted only Danish flint pebbles were used, whereas, during the test on the tube-mill, a mixture of Danish and French flint pebbles was used. We have always supposed that practically the whole difference in pebble consumption was due to the inferiority of the French pebbles. In fact, we have always considered the trunnion-discharge tube-mill and the Hardinge mill to be on a par as regards efficiency and costs of fine-crushing

Our first order was for six tube-mills for section No. 1, and for six Hardinge mills for section No. 2, our intention being to make a large-scale test of the two types of mills. However, we experienced a great deal of delay in delivery of the tube-mills and also a great deal of trouble due to faulty cast-steel heads for these mills. Finally we were obliged to order enough mills to remodel our entire concentrator without awaiting the results of any further testing. As we had experienced so much mechanical difficulty with the tube-mill, it was decided to order Hardinge mills, and we saw no good reason for ordering any other size than the one which we had tested, that is, 10 ft. diameter by 4 ft. cylinder.

It must be borne in mind that we had but six months in which to make mill tests and to decide on the kind of mill to be installed. It was imperative that the tonnage of the concentrator be increased, and that fine-crushing and flotation be installed with as little delay as possible; we realized that any considerable delay in this work would cost the company many times more than any loss which could result from our not installing, in the first place, just the right type and size of crushing mill. In other words, it would have paid us to replace our entire mill installation at the end of a year rather than to delay the installation for further testing. Fortunately, we seem to have chosen well in installing the 10 by 4-ft. Hardinge mill, and thus far have not found any

other type of mill which would give us better results. However, we have not by any means completed our investigation of other mills.

Second, in regard to the substitution of iron balls for pebbles: At the time we ordered the mills for our concentrator it was impossible to decide whether we would eventually use iron balls or pebbles, as very little testing had been done on the use of iron balls for this fine crushing. We had no idea whatever that a 225-hp. motor would pull a 10 by 4-ft. mill when loaded with balls. We decided on this particular size of motor as a compromise between what would be required for a pebble load (150 hp.) and what would be required for a full ball load (300 hp.). If we used pebbles, it would require e ght full-size mills per section, and if we used balls we figured it would require four or five mills per section, lagged down to about 8 ft. diameter. Here again we compromised by ordering six mills per section. In ordering the Hardinge mills we specified that they should be made sufficiently strong to carry a full ball load. If we decided to use balls, we planned to lag the 10-ft. mills down to about 8 ft., or whatever diameter was necessary to reduce the power requirement to 225 hp.

Third, Mr. Van Winkle states that the mills at Anaconda are 7½ ft. in d'ameter and about the same length; the mills are 7½ ft in diameter but the cylindrical portion is only 6 ft. long.

Fourth, Mr. Van Winkle is wrong in stating that the lagging of the Hardinge mills practically changed them into cylindrical mills. A Hardinge mill 8 ft. in diameter with a 6-ft. cylinder certainly cannot rightly be termed a cylindrical mill. It is true, of course, that it more nearly approaches a cylindrical mill than one which is 10 ft. in diameter with a 4-ft. cylinder. However, the important point in this connection is that the changing of the shape of the mill did not, in any way that we have been able to detect, increase the efficiency of the Hardinge mill. The one factor which was responsible for the great improvement in our crushing efficiency is the reduction in the speed of the mills.

As originally installed, the Hardinge mills (10 by 4 ft.) were driven at a speed of 23 r.p.m., as recommended by Mr. Hardinge, and pebbles were used as the crushing medium. When we converted these mills into 7½ by 6-ft. mills, by lagging, and used iron balls for crushing, we did not increase the speed of revolution to compensate for the reduction in diameter, as we believed that the mills were running plenty fast enough as they were. Later, we thought that maybe the mills were running too fast, that there was an unnecessary consumption of balls and power due to too much agitation, with its consequent waste of energy. Accordingly, we tried slowing one of the mills, making tests at speeds of 21, 20, 18, and finally 15 r.p.m. At the conclusion of these tests we decided that 15 r.p.m. was the most efficient speed for these mills. By reducing the speed from 23 to 15 r.p.m. we diminished the power consumption from

215 to 140 hp. per mill, and the ball consumption from 4.5 to 3.25 lb. per ton crushed.

The tonnage crushed, and the fineness of the crushing are just the same for the slow-speed as it was for the high-speed mill. In addition to the saving in power and balls, there s, of course, a considerable saving in lining and general repairs on the mills. However, considering only the first two items, our total saving amounts to 13,500 lb. of balls per day, and 2550 hp. for the copper and zinc mills. These two items show a saving in our operating expenses of over $250,000 per year. All of the mills in the copper and zinc concentrators have been operating at a speed of 15 r.p.m. since early in 1917.

C. T. Van Winkle (author's reply to discussions*).—On account of certain intimations, it seems necessary to state that I am not interested in any type of ball-mill. I am, however, interested in ball-mill crushing, and particularly in any methods which may cheapen this operation. I do not believe it is the desire of those interested in crushing to have their ideas molded by the mill manufacturers or their representatives. They should be allowed to form their own opinions after reviewing the data on various types.

While on a professional trip in Arizona in June, 1917, I visited the Inspiration plant a few days after the Marcy-Hardinge test was concluded, and was convinced of its absolute fairness. As stated in my paper, the results were given to the manufacturers and I subsequently secured Mr. F. E. Marcy's copies. My figures in Table 2 were taken from the original report sheets, and cover the average performance of these mills from April 4 to May 15, or a period of 42 days; the statement of Mr. Kennard, the Hardinge-mill operator, that my figures in Table 2 covered but one day is without foundation. I have stated that the lost time due to ball-mills at the Inspiration plant averages less than 0.4 per cent. This figure applies to the above test as well and bears out my statement that the test was run practically without delays on the Marcy-mill section.

It was not my purpose to discuss the relative detailed merits of two patented mills, but to describe the Inspiration test briefly and give the data as taken from the report sheets; also to set forth other facts and conditions pertaining to the conical mill. The Hardinge mill has become a type, due to its extensive use and its unique shape. Remarkable theories and claims have been published, and are therefore rightly open to investigation. I am familiar with some of the tests between the conical and the cylindrical mill, and know that such remarkable claims cannot be substantiated. I have reason to believe that some of the tests between cylindrical and conical mills have not been published because their

* Received Apr. 10, 1918.

publication would bring forth such replies as my paper has brought forth. Is the mining public willing to rest content in the belief that the conical mill is the last word in ball-mill crushing?

Professor John W. Bell sets forth one of the fallacies of the conical mill most clearly when he says, "Mr. Hardinge's 'hammer' theory is, I believe, a sound one; but unfortunately, at the very place in the Hardinge mill where there should be a large number of small 'hammers' there is room for only a few."

In Mr. J. Parke Channing's discussion, I note his company has cast its lot with the Hardinge mill. In my opinion, if they had cast their lot with an ordinary cylindrical overflow mill of the same diameter and equal cubical contents, a mill which anyone can build, easy to repair and operate, they would have secured superior results.

I wish to thank Mr. B. Britton Gottsberger for his discussion, giving the results attained when additional sets of rolls are used or additional stage crushing is adopted as compared with Inspiration. It is interesting and valuable information. His figure of 8.57 kw.-hr. per ton from mine rock to finished product is good.

The Inspiration coarse crushing figure as published[2] is 0.4 kw.-hr. per ton. Adding the 8.52 kw.-hr. given in my paper makes a total of 8.92. There should be added, also, the Dorr classifier power, which would probably bring the total up to about 9 kw.-hr. from the mine rock to the finished product, a difference of 0.48 kw.-hr. in favor of Miami. This, however, is offset by the additional stage crushing, trommels, an additional ball-mill, and Dorr classifier. The cost of 0.48 kw.-hr., or additional power saved, cannot be more than 0.5 c. One cannot operate an additional set of rolls, exclusive of power, for much less than 4 c. per ton, certainly not for 0.5 c.

One of the principal advantages Mr. Gottsberger has is the additional Dorr classifier capacity, using two 6-ft. and one 4½-ft. classifiers with an average tonnage of 987 tons per day, as compared with the Inspiration test figure of 1118 tons with two 6-ft. Dorr classifiers. This gives Mr. Gottsberger's plant more than 50 per cent. greater classifier capacity per ton than Inspiration. Many of us believe that increasing the circulating load increases the efficiency of the ball-mill. Personally, I think the increased classifier capacity is a big advantage. This same advantage the Hardinge mill had in the Inspiration test, but no mention was made of this on the report sheets. Inspiration might profit by using additional classifier capacity with its present mills.

The Inspiration mill building and the Miami mill buildings are the same size. The Inspiration has more than twice the capacity, not counting the two additional sections recently erected. This small space would seem to be a great advantage in the economy of milling.

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[2] *Engineering and Mining Journal* (Oct. 7, 1916), **102**, 678.

Referring to the discussion by Mr. E. H. Kennard, the Hardinge-mill operator, and representative of the firm in the southwest, the subject matter of his discussion does not come within the scope of my article, and lacks the prime essentials of a discussion. There were no excuses, or Marcy-mill breakages, recorded on the original report sheet; and my understanding is Mr. Hardinge could have continued his tests and experiments longer if he had wished.

To Mr. Albert E. Wiggin's discussion, I call attention that the actual net inside diameter or ball space of the re-built Hardinge mills at Anaconda, as given by Messrs. Laist and Wiggin,[3] is 6 ft. 8¾-in. Mr. Wiggin says "we have always considered the trunnion-discharge tube-mill and the Hardinge mill to be on a par as regards efficiency and cost of fine crushing." This is the opinion of other careful observers.

[3] *Trans.* (1916), **55**, 505.

Notes on Theory and Practice of Ball-milling Particularly Peripheral Discharge Mills

BY PIERRE R. HINES, MILWAUKEE, WIS.

(New York Meeting, February, 1918)

THESE notes are based on observations made while on a recent trip through the West, for the purpose of studying the practical operation of the ball-mill. The writer takes this opportunity to express his thanks for courtesies extended at the many plants visited as well as for the valuable data received.

While there are several types of ball-mill on the market, particular attention will here be given to the diaphragm type, as the open-trunnion type, especially the conical mill, has been thoroughly discussed in the *Transactions*.

There is a prevailing impression that the ball-mill is a recent development; however, ball-mills were used extensively in Montana and other western states for crushing ores for concentration as far back as 1898. Its present prominence is due in part to its recent successful application by one of the large copper companies. Without any reference to dry grinding, the first successful ball-mill for wet crushing, which is still in operation, was built 10 years ago.[1] This mill, designed by Erminio Ferraris for crushing Sardinian ores for concentration, is of more than passing interest. It embodies the peripheral discharge with grates, large forged-steel balls, and the principal features of the modern ball-mill. The results approach present-day practice, the chief differences being that the mechanical construction has been improved in the modern types.

Crushing Action of Ball-mill

The action of the balls and the principles of crushing have been studied by several investigators.[2] Their conclusions are confirmed by results obtained by the writer in experimenting with a small machine built at

[1] Erminio Ferraris: The Mechanical Preparation of Ores in Sardinia. *Trans.* (1908), **39,** 88.

[2] Hermann Fischer: Der Arbeitsvorgang in Kugelmühlen, inbesondre in Rohrmühlen. *Zeitschrift des Vereines deutscher Ingenieure* (1904), **48,** 437.

Walford R. Dowling: The Use of Scoop Discharges in Tube Mills. *The Journal of the Chemical Metallurgical and Mining Society of South Africa* (1915), **15,** 214.

the Allis-Chalmers factory, and serve to explain the reasons for some of the results obtained in practice. A ball-mill may be revolved so fast that the balls will cling to the shell during the entire revolution, while at slow speeds they will be carried up only a short distance and roll back. On the other hand, at the critical speed, they will cascade as shown in Fig. 1. At the critical speed the balls ascending on the layer next to the shell start from rest at a point S and cling to the shell without revolving or rolling, which has often been ascribed to them. These balls are held at rest by centrifugal force until they reach a point G, the location of which is dependent on the speed of rotation. Beyond the point G, gravity overcomes centrifugal force and the balls fall with increasing velocity in a parabolic curve which is the resultant of the above two forces, striking at a point W, the force of the impact being expended in crushing the material.

The several layers of balls lying on top of those next to the shell follow a similar cycle except that, due to relative difference in the two forces, their paths become more nearly vertical. The outer layers, spreading more than the inner layers, increase the area in the zone of the falling balls. Within the circuit thus formed is a neutral axis or a sluggishly rotating kidney-shaped mass in which little actual work is performed.

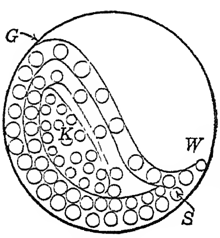


FIG. 1.

The material being crushed is thoroughly distributed throughout the mass by filling the interstices between the balls, and follows in the same circuit. It is, therefore, evident that the material is crushed mainly by impact of the striking balls as the whole mass falls. There can be very little grinding by attrition due to the rotation of balls, except at the point S where the shell picks up the mass and accelerates it to the rotative speed of the shell. The argument has often been advanced that fine material cannot be produced by impact alone and that fine grinding is done entirely by attrition or rubbing of adjoining balls. It is only necessary to break up a few small pieces of rock on an anvil with a hammer to prove that fines are unavoidably produced by impact. Screen analyses of the discharges from tube-mills in open and in closed circuits lead to the conclusion that in many instances an ore fragment may pass through the mill six to eight times before it is crushed to the desired fineness. Quoting directly from the article by Hermann Fischer referred to above:

> The grinding action, therefore, depends upon the height of the drop of the balls, *i.e.*, the height of the curve vertex above the point where the ball strikes, the speed of the shell, the weight and number of balls.
>
> The speed of the drum must be so determined that the curves can develop themselves properly. The weight of the balls and the height of drop are inter-related and their product must be sufficient to break the ore according to its size and hardness. Hard materials require heavier balls or greater height of drop than soft ones and

steel balls in small diameter cylinders will do the same work as flint pebbles in large diameter cylinders.

The free fall of the balls is dependent upon the volume of ball load. With a charge equal to or greater than half the volume of the mill the free fall of the balls is decreased, the charge is held together, and the size of the inactive kidney-shaped mass is increased. When the charge is about one-third of the volume of the mill the size of the kidney-shaped mass is reduced and the balls fall from their maximum free height. Operating results bear out the above facts in that the greatest number of tons crushed to a certain mesh per kilowatt-hour are obtained with ball charges equal to approximately one-third the volume of the mill

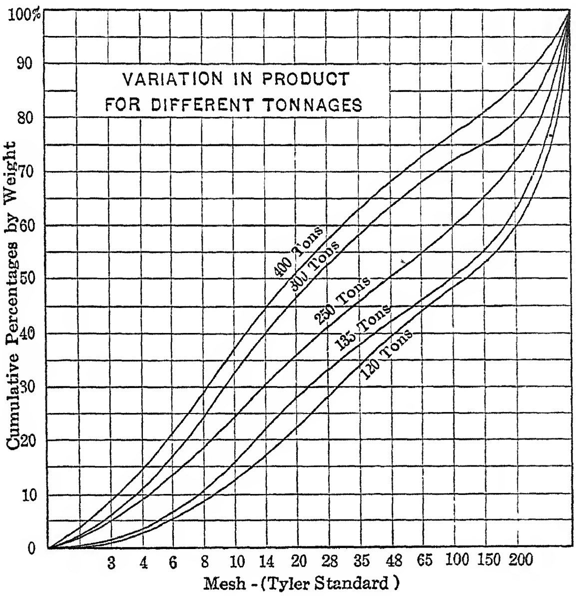


FIG. 2.

CONDITIONS DETERMINING FINENESS OF CRUSHING

There is a general impression that the grate acts as a screen or sizer. This is true to a limited extent, but it is not of primary importance. The fineness of product delivered by a ball-mill, the size of feed, ball charge, and speed remaining constant, depends upon the tonnage fed, the density of the pulp (water to solids ratio), size of balls, and, when operating in closed circuit, on the efficiency of the external classifying apparatus. The screen analyses plotted in Fig. 2 show the effect of varying tonnages, other factors remaining constant. They are from actual results with a 6 by 4-ft. mill.

The experience of operators at two western plants verifies the state-

ment that an assorted charge, containing a certain percentage of small balls, is desirable for a fine product.

The screen analyses plotted in Fig. 3. show the difference in product when the initial charge included only 5-in and 2-in. balls, and when the same charge contained a large percentage of 4, 3, and 2-in. balls. In some respects, these results do not agree with what would be expected, but I will not attempt to propound a theory to explain the deviations at this writing.

The peripheral-discharge mill differs from a trunnion-discharge mill, in the character of its product in that a small amount of moisture will

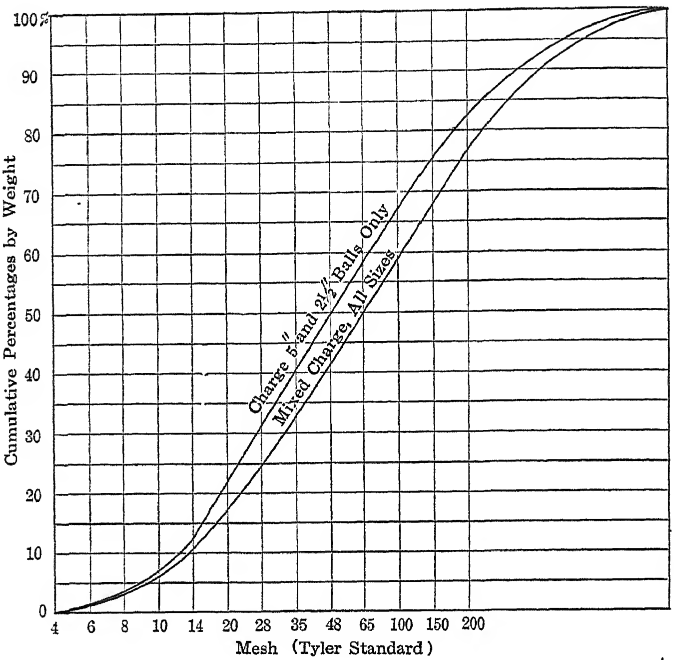


FIG. 3.

give a fine product and a large amount a coarse product. As the discharge is entirely at the periphery, and does not depend upon any classifying action to overflow the finished product, the greater the amount of water added the quicker the pulp will pass through the mill and the coarser the product.

In mills provided with means for raising the discharge or pulp level from the periphery to some intermediate height between the periphery and the trunnion, the fineness and the amount of oversize can be controlled within certain limits. No figures are available showing these differences, but from practical results in the field it appears that a wide variation can be obtained by this means.

The grate should, of course, retain some oversize, but this action can be carried to extremes, especially when a fine product is desired, as the consequent diminished capacity is not compensated by the reduction of oversize. In all cases when a fine product is desired, it is advisable to run the mill in closed circuit with an efficient external classifier. The principal function of the grate is to retain the ball charge in the mill, while permitting a peripheral discharge. The efficiency of the classifier, when a ball-mill is run in closed circuit, directly affects both tonnage and fineness. This will be discussed under capacity.

Conditions Affecting Ball-mill Capacity

Capacity of ball-mills depends upon the following factors: fineness of grinding, weight or volume of ball charge, hardness of material, size of grate openings, and size of balls, other factors remaining constant. Practically speaking, the most important limiting factors for capacity have

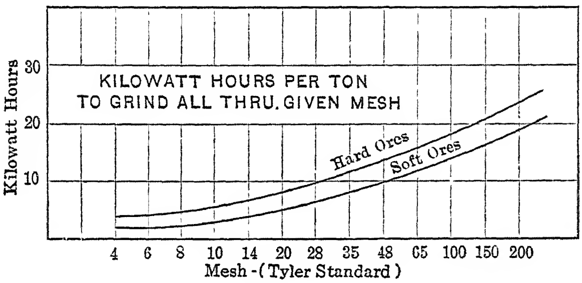


Fig. 4.

been the size of the feed opening in the trunnion, the type of trunnion liner, and the type of feeder.

As previously shown, tonnage and fineness are inter-related and the capacity of a ball-mill should be figured on the following basis when sufficiently reliable figures have been collected. The kw.-hours required to crush a ton of ore from and to a certain mesh should be arrived at from average operating conditions. A ball-mill has a certain definite maximum power rating depending upon its ball load. Multiplying the kw.-hours per ton by the tons required to be crushed per hour, the product will represent the power required, and the mill nearest to that power rating should be selected. Fig. 4 is a preliminary power curve based on the recommended maximum ball charge, together with all available data at hand at the present time; however, 60 or more carefully taken power records would be needed for even an approximately correct curve.

Operating a mill at less than its maximum capacity for a given ball charge will result in excessive wear on lining and balls and produce a finer

product than necessary. To crush a ton of ore of a certain hardness and size to a given fineness represents a definite amount of work; hence the capacity of a mill depends upon (*a*) the hardness, and (*b*) the ratio of reduction, the latter affecting capacity far more than the former.

It is useless to expect a large capacity from a mill operated with balls of a size too small to crush the ore, or when the balls are of a composition that will not withstand the shock of impact and shatter themselves to fragments. Hard ores, when fed direct from a crusher, require a proper percentage of 5-in. steel balls to do effective work. A 4-in. steel ball is often sufficient for some of the softer porphyry ores. Smaller steel balls may be used for regrinding work, but the charge should contain a per-

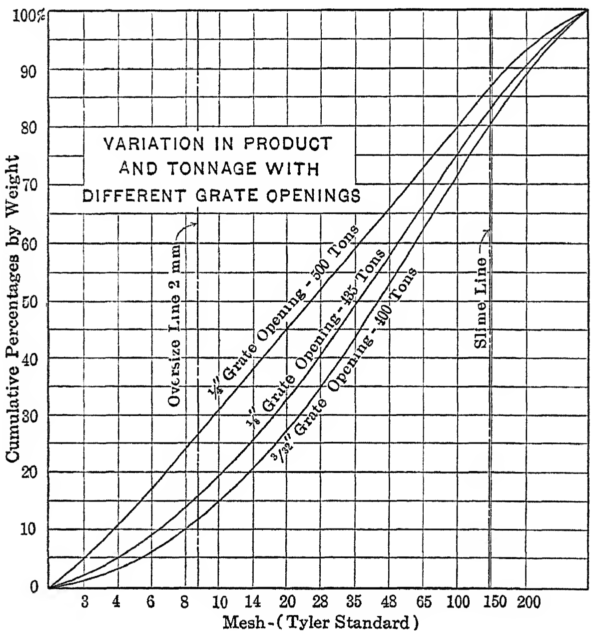


FIG. 5.

centage of 2-in. steel balls when working on hard ores. For regrinding soft ores, cast iron or composition balls may be used.

Where a fine product is desired together with a minimum amount of oversize, the grate opening should not be diminished. Smaller grate openings will reduce the amount of oversize but the decreased tonnage is not compensated. In such cases it is advisable to depend on an external classifier and operate the mill in closed circuit; the grate bars should be set with at least ⅛-in. opening. Where a coarse product is desired, for example for concentrating table work, the grate may be used as a sizer and an open-circuit scheme adopted.

Fig. 5 shows a typical example of the variation as to both tonnage and product that can be obtained with different grate openings.

When the mill is operated in closed circuit the efficiency of the classifier directly affects the capacity and it is important that the classifier be of proper size and properly operated. In one case observed, a classifier of the mechanical drag type was set with the wrong slope; correcting the slope approximately doubled the capacity of the mill. Classifiers of the mechanical drag type, in order to make an efficient separation, must be operated with proper consistency of pulp in the classifying zone, the slope and length of the sand plane must be correct, and the speed of the drag must be suited to the material.

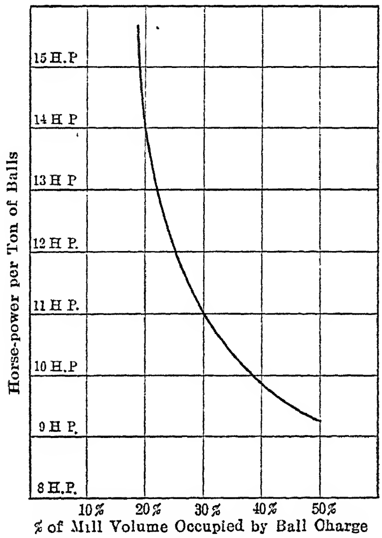


FIG. 6.

CONDITIONS AFFECTING BALL-MILL POWER

Power depends principally upon the weight of ball charge, an approximate figure being 9 to 10 hp. per ton. However, the power per ton of balls will vary according to the percentage of volume the ball charge occupies in the mill. An approximate curve from data at hand is given in Fig. 6, from which it will be seen that the power required per ton of balls is least when the mill is loaded half full and that the curve rises very rapidly as the ball load is reduced. A charge greater than half full causes a balancing effect until, when the mill is full, the power required is practically only that necessary to take care of friction after starting.

When the volume of ball charge is reduced, within certain limits, the power consumption per unit of ball charge is increased, because the center of gravity of the charge is further from the axis of the mill; but as

the mass of balls is more active and circulates more freely, the crushing efficiency is increased proportionately to the increase in power consumption per ton of ball load.

There are a number of ball-mill installations for fine crushing in the West. Most of these are arranged in two or more stages where a product finer than 100-mesh is desired, and there seems to be little difference of opinion as to the advantage of such an arrangement. Where coarser products are desired, say through 48-mesh, both single-reduction and stage-crushing installations are found. Stage crushing seems to have higher efficiency, but when first cost and simplicity are considered, the single-reduction installation seems to be more desirable, especially for small plants.

The curves (Fig. 7) plotted from recent tests show the power required per ton of material crushed under varying capacities. It can be seen that the power rises rapidly at the expense of capacity when a fine product

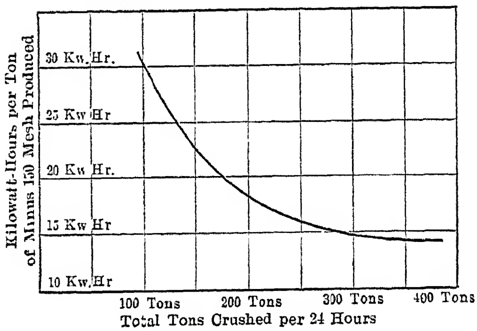


Fig. 7.

is desired, and when compared with an average power curve it would make a saving to run a large tonnage through several stages. The phrase "single reduction" as applied to ordinary ball-mill practice is misleading, because in the most common application of the ball-mill, running in closed circuit for preparing feed for flotation, a great deal of the material is returned from once to six or seven times before it is finally reduced. The most efficient installations in practice are undoubtedly those which have a large return circuit and the mill is crowded, making a small reduction at each pass through the mill, but handling a large tonnage at the same time.

Special Fields for Ball-mill Crushing

The ball-mill is not to be recommended for all and sundry problems in the milling field. It is not suitable for concentration work where the ore contains a large amount of coarse mineral easily pulverized. Where

crushing to 12-mesh and finer is necessary to release the mineral, the ball-mill makes a suitable product when properly operated, and is as good as any other regrinding machine. The installation of concentrating

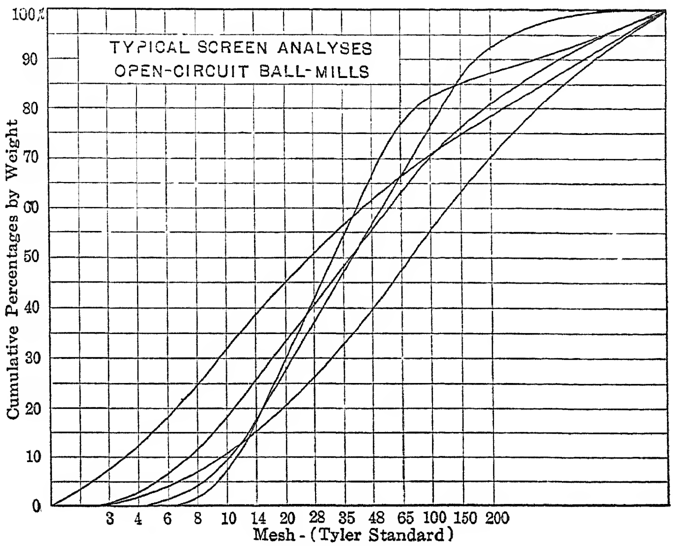


Fig. 8.

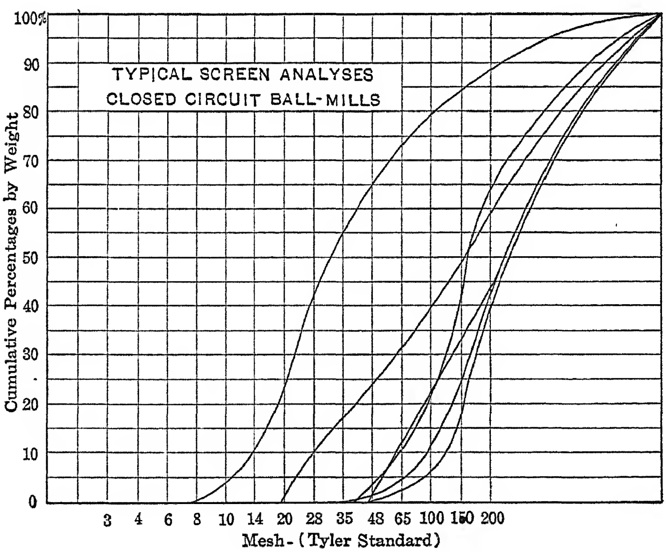


Fig. 9.

tables within the mill circuit, as practised at Stoddard, Ariz., is a notable advance in this class of work. The special field of the ball-mill, however, is for products 20-mesh and finer.

The use of ball-mills for reducing crusher product to 85 per cent. below 200-mesh in two stages, as practised at the United Eastern, Tom Reed, and Montana mines, in Arizona, is a distinct advance in fine crushing. The simplicity, small floor space and large capacity of these installations are especially notable. While there is not such economy in power nor so small a number of repairs as compared with a stamp-battery and tube-mill plant of the same capacity, the operating troubles and attendance are much reduced.

The curves in Fig. 8 and 9 show typical screen analyses of ball-mill products, to give a better indication of the class of work that may be expected.

Ball-mill Feeding

The most desirable method of feeding coarse material is the arrangement as installed at the Tom Reed mill. The crusher product is fed direct from a bin to an apron feeder, the speed of which is controlled by a Reeves variable-speed transmission device, having a small hand crank, sprocket, and chain conveniently situated for the mill operator. This insures absolute control and allows quick changes.

When a ball-mill having a proper crushing load is rotated at the critical speed, the balls strike at a point on the periphery about 45° below horizontal, or S in Fig. 1. An experienced operator is able to judge by the sound whether a mill is crushing at maximum efficiency, or is being over- or under-fed. Excessive rattling denotes under-feeding; a sound of impact at W (Fig. 1) indicates overloading; while under proper conditions, the impact will be heard near S.

When a ball-mill fitted with a diaphragm is over-fed, the mill fills up to a certain level, then stops crushing and discharges any additional feed back through the feed trunnion. Once over-fed, it takes from 30 min. to 2 hr. to free itself. Ball-mills, therefore, should be provided with a central opening in the diaphragm connecting with the discharge trunnion, to prevent over-feeding and the delays incidental thereto.

The greatest difficulty in feeding most ball-mills, when running on large tonnages and coarse feed, say, ½ to 3 in., is due to the restricted area of the feed trunnion, which limits the quantity of coarse material that can be fed through it. A few simple calculations will show the velocity necessary to pass a given quantity feed through the trunnion, It can also be shown mathematically that the average spiral in the trunnion liner does not advance the feed rapidly enough; therefore. instead of aiding, it retards the feeding. These results are confirmed in practice. A smooth liner, tapering from the feeder into the mill, does not retard the flow of the feed, and is, therefore, more efficient than the spiral. Experiments with small models, as well as experiments in the

field, corroborate these conclusions. A short trunnion with large diameter is essential for feeding a large tonnage to a ball-mill.

The engineering department of the Allis-Chalmers Manufacturing Co. has recently conducted some experiments with feeders modeled after the various types in use, on a scale of 1 in. per foot. The feeders were operated at constant speed conformable with present practice, the material delivered in a given time being weighed. The following con-

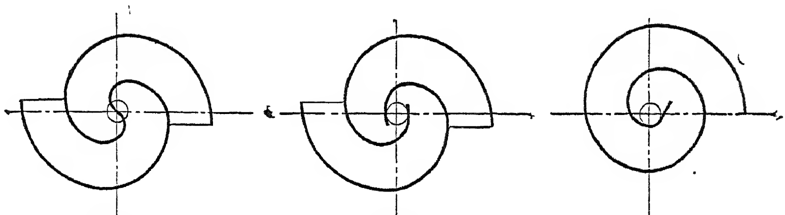


FIG. 11 FIG. 10 FIG. 12

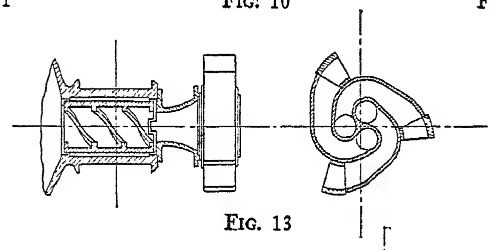


FIG. 13

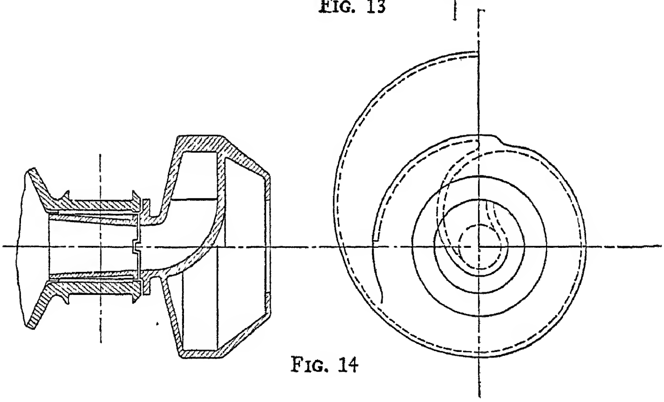


FIG. 14

FIGS. 10 TO 14.

clusions were drawn: "The intake of a single-scoop feeder has far greater capacity than the throat or trunnion of the mill, and there is no good reason for using a double- or triple-scoop feeder, the capacity of the feeder not being controlled by the quantity it will pick up, but by the quantity that it can discharge through the throat or trunnion." These experiments further demonstrated that the capacity of a spiral feeder is in direct proportion to the length of the path of the spiral. In other words, a spiral feeder embodies all the principles of the Frenier sand pump, in

which the long path of the spiral increases the pressure which forces the feed into the trunnion opening.

Fig. 10 shows a double-scoop feeder without a partition; Fig. 11 shows the same feeder with the two spirals connected across the center of the trunnion opening, making a partition so that the material taken up cannot drop from one scoop into the other. Fig. 12 shows a single-spiral feeder; Fig. 13 shows a triple-spiral feeder; and Fig. 14 shows a standard combination feeder which has a single spiral.

Disregarding the influence of the trunnion liner as determining the relative capacity of feeders, the experiments demonstrated that No. 12, the single-spiral feeder, has the greatest capacity; No. 11, double-spiral feeder with the partition across the trunnion opening, gave the next best capacity, which, however, was less than 50 per cent. that of No. 12. The capacity of No. 10 was only about 25 per cent. that of No. 12. The capacity of the triple-scoop feeder, Fig. 13, was but very little greater than that of No. 11. The results clearly demonstrate that increasing the number of spirals or scoops does not add to the capacity of a feeder.

Consistency of Pulp

The ratio of moisture to solids is important in ball-mill work. From actual operation it has been observed that fine grinding is best done when water constitutes 33 to 40 per cent. of the pulp, or the water-to-solids ratio is 1 : 2 or 1 : 1½. Where a minimum of fine material is desired, 50 per cent. and upward of water is desirable.

Ball Consumption

Ball consumption varies with the fineness of the product, hardness of the ore, quality of ball, and whether a mill is run in closed or open circuit. The ball consumption for mills delivering a coarse product, all passing 8-mesh and containing 10 to 20 per cent. below 200-mesh, the mill being run in open circuit, is about ½ lb. per ton for steel balls and 1 lb. for cast composition balls.

The average ball consumption for mills in closed circuit has been plotted in Fig. 15 for steel balls and for cast composition balls. Enough data are not available to plot curves for hard and soft ores, and individual figures will vary considerably from the average of the curves, which are given merely a guide as to what may be expected and also to show the increased consumption with finer grinding. It should be noted that the curves apply to products practically all of which are finer than the meshes indicated, up to 65-mesh. Points on the curves representing finer products are for mills generally regrinding 10- to 20-mesh feed; hence corresponding amounts must be added to give the total ball consumption for reducing from crusher size to 100-mesh and finer.

Consumption of Liners

Average consumption of shell liners, for both chrome and manganese steel, is ⅓ lb. per ton of ore crushed. The consumption of lining seems to be fairly constant regardless of the hardness of the ore, fineness of product, or other conditions. The greatest wear on the lining is probably caused by the impact of the balls and by their slippage on the shell during the period of acceleration. If the mill is running below capacity the wear will increase.

There are numerous types of liners on the market, and improvements are constantly being made, but the greatest improvement made recently

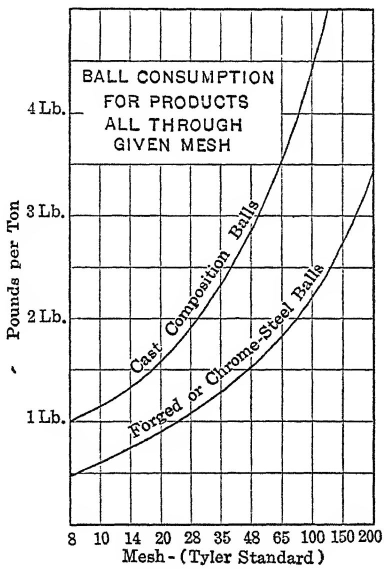


Fig. 15.

is the general increase in weight and thickness. The proportion of scrap has been very high, and the consumption stated above may be reasonably expected to be diminished with heavier and thicker liners. Regarding the shape of liner, there is considerable difference of opinion. The smooth liner is probably as efficient as any of the others if run at slightly higher speed.

Hard-iron liners have not been found satisfactory when used with balls of 5 and 4-in. diameter, as they have invariably failed by cracking and breaking, but with balls of 2-in. diameter and smaller they are sufficiently durable. It is possible that a heavy hard-iron liner backed and set in cement mortar might be successful, but this has not yet been tried as far as we know.

The loosening of liners may be avoided by using deeply countersunk bolts of large diameter with double nuts. When the liners are first put in place, after running the mill for several hours the bolts should be gone over again and the nuts tightened with a short wrench and hammer. Later, after the feed is on, they should be gone over once more. Leakage around bolt holes is caused entirely by lossening of the bolts due to lack of tightening or a worn-out lining. If candle-wicking is used as packing around a bolt, between the shell and the washer, and the nut is kept tight, no leakage will occur until the liners are worn out.

A New Method of Separating Materials of Different Specific Gravities

BY THOMAS M. CHANCE, WASHINGTON, D. C.

(New York Meeting, February, 1918)

ALL gravity methods for the separation of ore from gangue, or of slate and other refuse from coal, are based upon differences in the falling velocities, in some fluid medium such as air or water, of the materials to be separated. As all materials falling in a vacuum have the same velocity, independent of the size, shape, weight or specific gravity of their individual particles, it would be more accurate to describe the operation of these methods as depending upon the *retardation* of falling velocities effected by the resistance of a fluid medium, this retardation being greater for small or light particles than for large or heavy particles. This generalization is true also of those appliances utilizing centrifugal force to replace or to supplement the action of gravity.

The separation of materials of different specific gravities by means of a fluid having a specific gravity greater than that of the lighter particles and less than that of the heavier particles has not been applied commercially, or on a large scale, to the separation of ores or to the washing of coal, the method being limited to laboratory experimental work or to laboratory determinations for the purpose of checking up the work of jigs, classifiers, and other types of concentrating appliances. A solution of zinc chloride has thus come into general use in the laboratory to separate coal, bony coal, and slate, both to check up the work of coal-washing plants and for the purpose of making tests preliminary to the designing of coal-washing plants.

The use of a heavy solution of some chemical in water has often been proposed for making such separations, especially in connection with the washing or preparation of coal. Practically insuperable difficulties, however, have prevented the commercial development of any such process, the difficulties being both physical and financial. The cost of the chemical used to make high-gravity solutions is usually prohibitive, and the freeing of the coal from all traces of the chemical is found to be practically impossible. Such solutions inevitably penetrate the individual lumps and particles of coal, transfusing into the pores and saturating the joint-planes, and very large quantities of wash water

would be required to free the prepared product from the chemical with which it was thus contaminated. The use of large quantities of wash water renders it practically impossible to recover the chemical for subsequent use at a reasonable cost, because this requires concentration by evaporation of the wash water.

The method which it is the object of this paper to describe is based upon the facts that any relatively finely comminuted insoluble solid matter (such as sands), if mixed with a certain quantity of liquid (such as water), can be maintained suspended in the liquid by continuous agitation, and that the mixture, so long as agitation is maintained, will form a mass exhibiting physical properties similar in every respect to those of a fluid of relatively high specific gravity, including its ability to float solid bodies having less specific gravity, while permitting solid bodies of greater specific gravity to sink in it.

The agitation of such a fluid mass may be effected and maintained by any suitable mechanical appliances, or by introducing liquid under pressure into the fluid mass, either as jets or as a slowly rising current. When a fluid mass of a certain predetermined specific gravity has been produced in this manner, its specific gravity will remain constant so long as the agitation applied to it is not varied. The specific gravity of the fluid mass will be diminished by increasing the agitation (provided the necessary additional liquid is supplied for dilution of the fluid mass); while its specific gravity will be increased if the agitation be diminished.

We have found that a mixture of sand and water can be used to produce a fluid mass having a specific gravity suitable for the separation of coal from bony coal, slate, fireclay, pyrite, and other impurities. We have used sand ranging from 20- or 30-mesh down to 100- or 200-mesh, or even finer, and find that fluid masses with specific gravities ranging from 1.20 to 1.75 are easily produced and can be maintained constant for an indefinite period at any desired gravity within these limits. In our investigations we have effected agitation by stirring arms, by propeller blades, by rotating discs and cones, by hydraulic jets, by upwardly rising liquid, and other means; we have also tried combinations of hydraulic and mechanical agitation, and have found that a very wide range of appliances can be used to produce the desired agitation.

We have also found that fluid masses having specific gravity high enough to float quartz, feldspar, limestone, and other rocks, can readily be produced by using magnetic iron-ore sand and water instead of quartz sand and water. Other heavy materials can be used, such as ore concentrates of galena, metallic copper, etc., for producing fluid masses having very high specific gravities.

For the practical separation of materials of different specific gravities by this method, the following observations are evident:

1. Every particle of material having lower specific gravity than that

of the fluid mass will float; that is, the separation will be independent of the size of the materials to be separated. If the fluid mass be contained in a receptacle large enough to permit the introduction of large lumps, it is possible to dump into it the ore or coal, as mined, without any preliminary sizing, whereupon, every particle of less specific gravity than the fluid mass will float, irrespective of its size or shape.

2. As every particle of material, irrespective of its size or shape, having greater specific gravity than the fluid mass will sink, no pre-

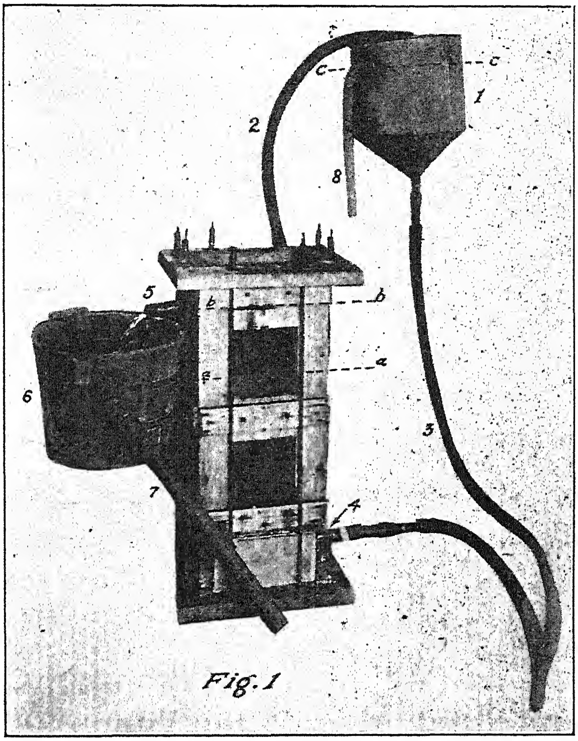


FIG. 1.—TESTING APPARATUS, PERSPECTIVE VIEW.

liminary sizing is necessary to insure the sinking of all material having a higher specific gravity than that of the fluid mass.

3. The insoluble material, such as sand, used for producing the fluid mass can readily be washed from the materials which have been so separated, and thus can be recovered and returned to the fluid mass for continuous use.

This method offers facilities for making differential separation of materials which may be of nearly the same specific gravity, because the fluid mass can be so adjusted as to float one material while permitting the other to sink, although the difference in their specific gravities may

be slight. This characteristic can be applied to the separation of low-ash coal from high-ash, of coal from bony coal, or of bony coal from slate; and with ores it may be utilized for separating waste rock from rock that contains sufficient ore to justify crushing and concentration, as well as for the separation of ore-bearing minerals of different specific gravities.

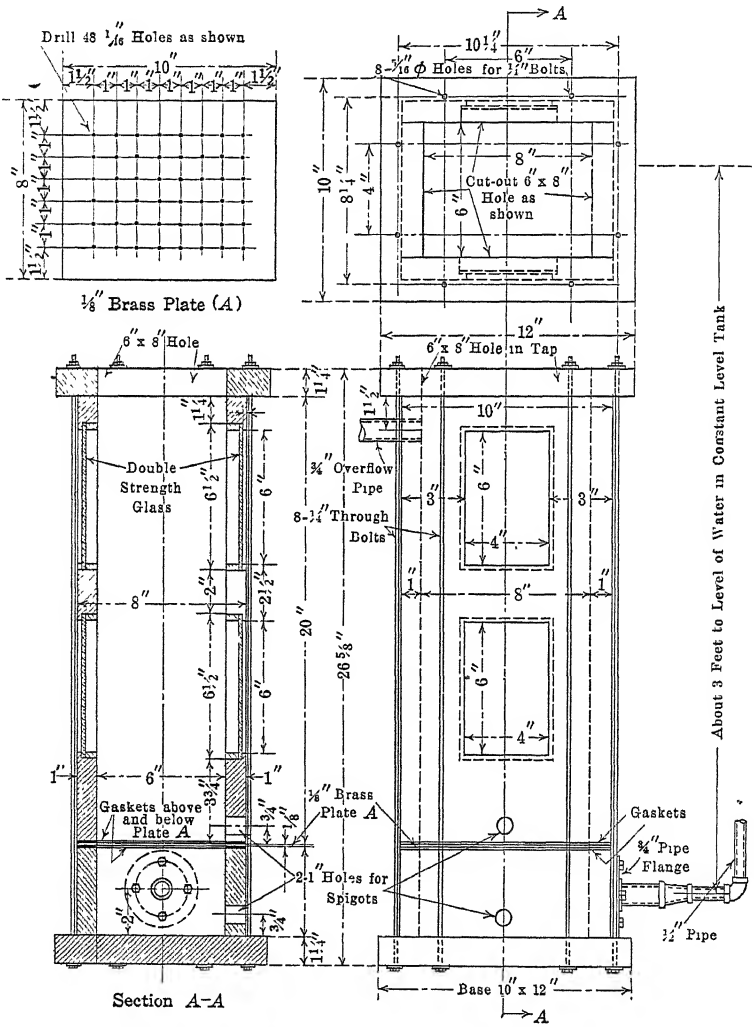


FIG. 2.—TESTING APPARATUS, WORKING DRAWING.

The development of this method has been so recent that we have not yet introduced it commercially, our energies having been directed to perfecting appliances suitable for the operation of the method. It is evident that such apparatus may be built in a great many different forms. Much experimental work has been done to determine the conditions under

which a satisfactory agitation of the fluid mass can be obtained and maintained, but we have found no difficulty in securing the desired results with many different types of agitators.

An apparatus in which "float and sink" tests may readily be made on coal, bony coal, and slate, is shown in Fig. 1, and a working drawing is shown in Fig. 2. The apparatus consists of a vertical box open at the top, 6 in. wide by 8 in. long and 20 in. high. The bottom is closed by a

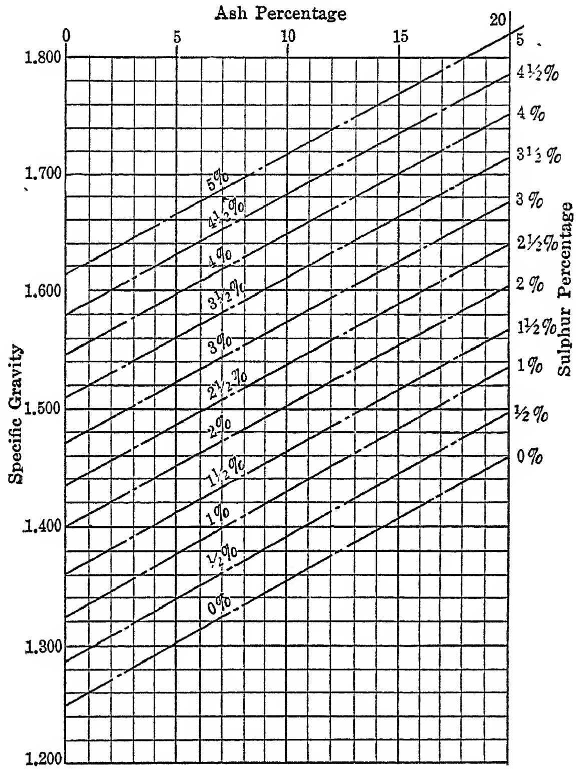


FIG. 3.—RELATION BETWEEN SPECIFIC GRAVITY OF COAL AND ITS PERCENTAGE OF ASH AND SULPHUR.

(Based on following factors: Pure coal, sp. gr. = 1.25. Clay ash, sp. gr. = 2.3. Sulphur, 1% = 2% FeS_2, having sp. gr. = 4.9.)

brass plate (4) ⅛ in. thick, having 48 round holes of $\frac{1}{16}$-in. diameter, spaced 1 in. apart. Below this brass plate is a water-tight box supplied with water under pressure from the tank 1, which receives water from a supply hose 2, and delivers it through the hose 3 to the box below the brass plate. These two boxes are fastened together with eight bolts running from top to bottom, and the joint at the brass plate is made water-tight by gaskets. The vertical box is provided with two glass windows and with an overflow 5 emptying into the bucket 6, in which

any sand carried out by the overflow may settle; the bucket has an overflow pipe 7 through which the water is discharged.

The water in the tank 1 is maintained at constant level *c–c* by the overflow pipe and hose 8, so that the effective hydraulic head, the vertical distance between the overflow lines *b–b* and *c–c* is maintained constant, but can be adjusted by raising or lowering the tank 1. If the

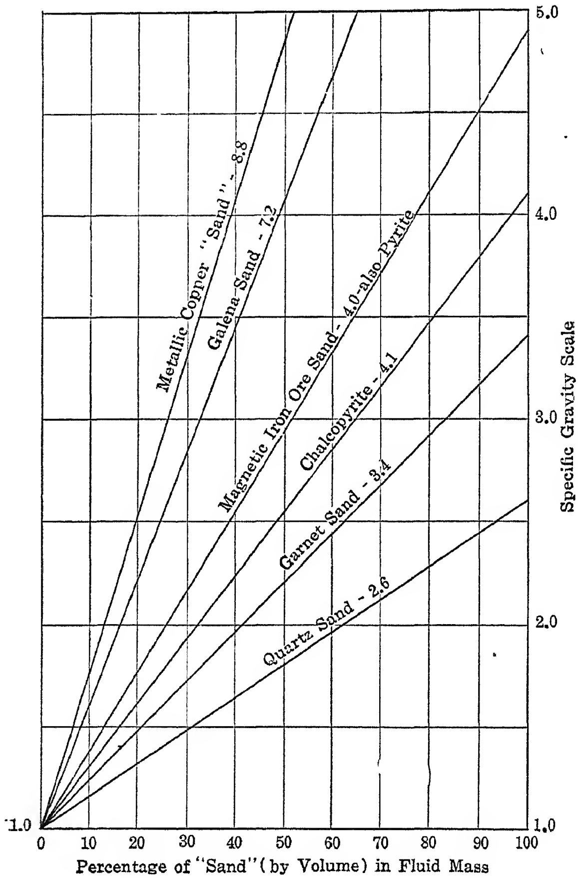


FIG. 4.—SPECIFIC GRAVITIES OF FLUID MASSES CONTAINING STATED PERCENTAGES (BY VOLUME) OF VARIOUS MINERALS IN GRANULAR FORM.

tank 1 be raised, increasing the agitation, the level of the fluid mass *a–a* rises and the specific gravity of the fluid mass is correspondingly reduced; if the tank 1 be lowered, diminishing the agitation, the level of the fluid mass sinks below the line *a–a*, correspondingly increasing its specific gravity.

In apparatus of this type, agitation being effected by hydraulic water alone, we have found that with mixed sands averaging 80-mesh, and working under a relatively low head, efficient agitation may be obtained by

the use of 3 to 10 gal. of water per minute per square foot of horizontal area of the apparatus. When mechanical agitation is used in combination with hydraulic water, the quantity of water can be reduced.

The importance of this method as applied to coal washing is illustrated by Fig. 3, which shows the theoretical increase in specific gravity of bituminous coal due to the presence of ash and sulphur (present as pyrite).

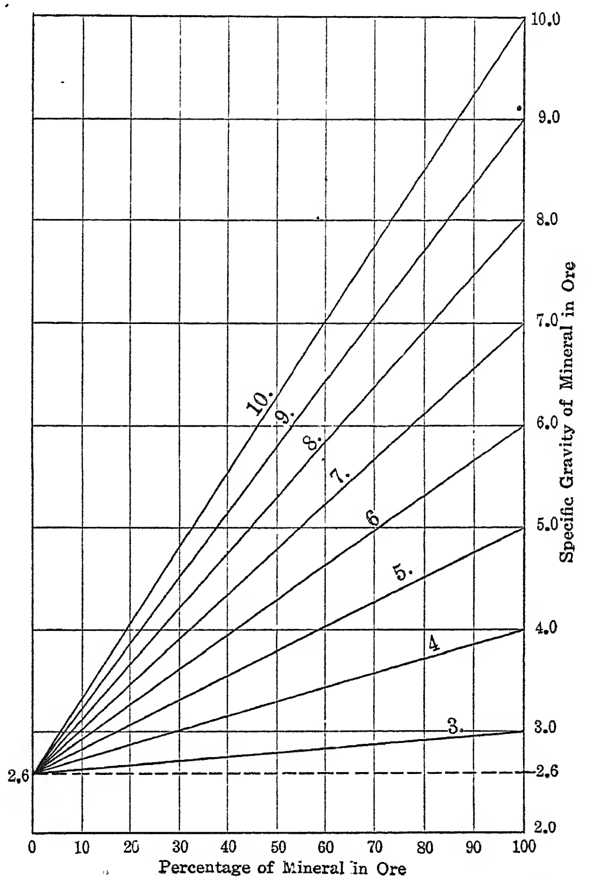


FIG. 5.—SPECIFIC GRAVITIES OF ORES CONTAINING STATED PERCENTAGES OF MINERALS OF DIFFERENT SPECIFIC GRAVITIES IN A GANGUE OF QUARTZ (SP. GR., 2.6).

The specific gravity of coal is naturally increased more by high sulphur percentages (due to the high specific gravity of the pyrite) than by high ash. Thus an "ash-free" coal containing 3 per cent. of (pyritic) sulphur will have a specific gravity of about 1.47, while a "sulphur-free" coal with 20 per cent. of ash would have a specific gravity of 1.46.

As coal of relatively light specific gravity is low in both ash and (pyritic) sulphur, the method offers a means for separating pure coal from that which is relatively impure, without fine crushing of the whole

mine product. Assuming the machine be set to produce a fluid mass of 1.40 specific gravity, and bituminous coal (run-of-mine) be fed into the washer, every lump and particle of low-ash and low-sulphur coal will float, while every lump and particle of high-ash and high-sulphur coal will sink, together with all the bony coal, slate, pyrite, and fireclay. The coal that floats is a very high-grade finished product. The material that sinks can be removed and passed into a second washer, in which the fluid mass is maintained at a specific gravity of, say, 1.60. Here all the slate, fireclay, and pyrite sinks, and also the very high-sulphur (4 to 6 per cent.) and very high-ash (15 to 20 per cent. ash) coal, but all the coal of intermediate density will float and constitute a product suitable for general use. If it be desired to improve the intermediate product, this can be done by crushing and subsequent separation in the same or another machine. The charts shown in Fig. 4 and 5 will be useful in adapting the preceding principles to the separation of metallic ores.

DISCUSSION

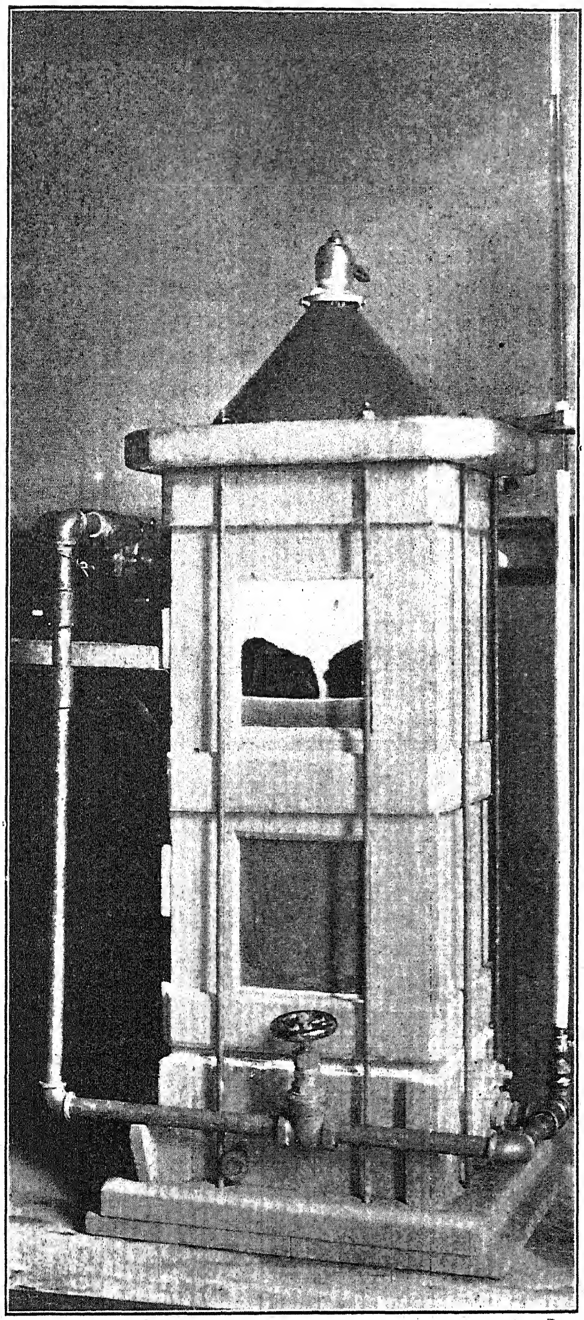
[This paper was presented for the author, who is now in the National service, by H. M. Chance, and was illustrated by a working model built to the plans shown on page 266. For more convenient operation, a small motor-driven centrifugal pump was attached to the overflow outlet (5, Fig. 1, p. 265) delivering to the inlet, 4. The pressure of ingoing water was then adjusted by a valve at 4, and was indicated by the column of water in a vertical glass tube connecting with the pressure chamber; an average pressure of 15 in. of water column was maintained during the demonstration. (See Fig. 6, p. 271.)

The sand used in the test was beach sand, which had simply been passed through a 20-mesh screen; about 45 per cent. was finer than 80 mesh. The circulation of water was at the rate of about 5 gal. per square foot per minute, and the rising velocity of the water in the box as a whole (not the velocity of the jets) was 6 in. per minute. At this consistency, the specific gravity of the fluid mass was between 1.55 and 1.60.

Mr. Chance estimated that it would be possible to maintain a fluid mass of this consistency, 3 ft. deep, and with an area of 50 by 60 ft. with an expenditure of 15 hp. Mr. Chance then showed how a lump of coal would float on the fluid mass, and also made a separation of slate from coal on a small scale in a wire cage submerged momentarily in the fluid.

The following demonstration relates to a matter not contained in the original paper, and was presented as of interest to the operators of cyanide and other lixiviation processes dealing with fluid mixtures of varying specific gravity.—*Ed.*]

H. M. Chance, Philadelphia, Pa.—Upon immersing a tube, open top and bottom, a certain depth in the fluid mass, the tube is at first



Height of water in tube shows pressure under which water is supplied to bottom of apparatus below the perforated brass plate, through which it issues as jets that keep the sand and water above this plate constantly agitated, thus producing a fluid mass of high specific gravity.

Electric light to illuminate the interior.

Electric motor driving centrifugal pump.

Top of clear water in the apparatus.

Lumps of coal floating in fluid mass, about one-half in sight.

Top of fluid mass consisting of an agitated mixture of sand and water.

Material seen in window is the lower part of the fluid mass, evidences of the jets can be seen in left half of window.

Brass plate with perforations $\frac{1}{16}$ of an inch in diameter and spaced 1 inch apart.

Valve to regulate pressure and volume of water pumped from the top of the apparatus into the chamber below the perforated brass plate.

FIG. 6.—IMPROVED FORM OF APPARATUS AS INSTALLED FOR DEMONSTRATION.

filled with the fluid mass and superincumbent water, the water at first standing within the tube at the level b, coinciding with the top of the water in the apparatus. After a few minutes the water within the tube rises to the level a. This phenomenon is due to the fact that there is no agitation within the tube to prevent the sand from settling, because the tube has no overflow. The sand therefore drops through the tube, settling to the bottom and joining the fluid mass external to the tube, so that the whole tube from the bottom up to a becomes filled with water, being sustained at the height a by the hydrostatic pressure exerted by the greater specific gravity of the fluid mass. It is evident that that part of the column of water between b and c is counterpoised by the water exterior to the tube between the same levels, so that we may neglect this part of the column as having no effect. We are therefore concerned only with the depth of water within the tube between a and b, and c and d (Fig. 7).

$$\text{Sp. gr. of fluid mass} = \frac{cd + ab}{cd}$$

For example, if cd is 10 in. or 10 ft., and ab is 6 in. or 6 ft., sp. gr. = $(10 + 6) \div 10 = 1.60$.

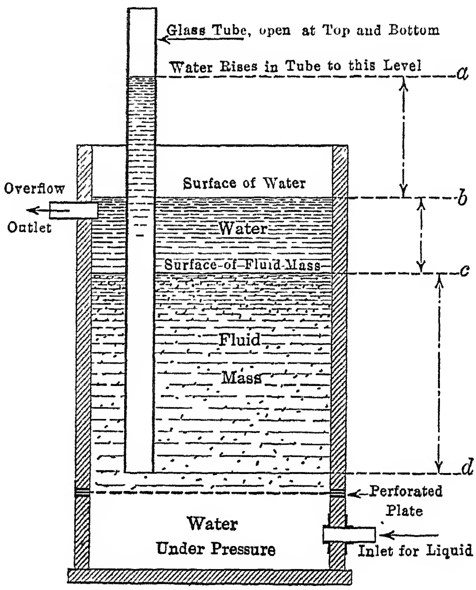


FIG. 7.

The weight of the solids (held in suspension by agitation) from c to d is equal to the weight of the column of water from a to b, irrespective of the specific gravity of the solid matter held in suspension. The depth of water, b to c, may vary from zero to any desired depth.

Not only can the specific gravity of the fluid mass be determined by

this method, but the *actual weight* of the materials held in suspension by agitation, irrespective of the specific gravities of the individual particles (which may vary widely) is exactly equal to the weight of a column of water between a and b. It will also be noted that this method of measuring specific gravity of an agitated fluid mass gives the average specific gravity from the top to the bottom of the mass; whereas the hydrometer method in common use gives the specific gravity at the depth to which the hydrometer is immersed. In many cases in treatment of ore pulps the specific gravity of a fluid mass may be considerably greater at the bottom than at the top.

It will be evident that the specific gravity of such a fluid mass, and also the weight of the solid matter held in suspension in such mass, can be measured by a pipe or tube *external* to the tank containing the pulp. All that is necessary is to insert a pipe near the bottom of such tank, extending up vertically a sufficient distance above the top of the receptacle. It may also be noted that if the pulp contains considerable quantities of colloidal material, that such pipe can be kept free from this and kept continuously filled with *clear water* by feeding a very small stream of clear water into the top of the pipe.

The United Eastern Mining and Milling Plant

BY OTTO WARTENWEILER, LOS ANGELES, CAL.

(New York Meeting, February, 1918)

After the phenomenal development of the new mine, the United Eastern Mining Co., with Mr. Frank A. Keith as President, decided to install a reduction plant.

The character of the ore, closely resembling the product of other mines in the district, did not offer any particular metallurgical problems, since these neighboring mines had been operating milling plants very successfully for several years. Thus, with the general metallurgical treatment fairly well-defined, the matter of next importance was to design and construct a plant as economically as possible, that would give the best results obtainable.

The ore consists of a mixture of calcite and quartz in about equal quantities, with some decomposed andesite, while the average value of mill feed was calculated to be $20 or more in gold, no silver being present. The tonnage to be treated at the start was fixed at 200 tons, but, in view of the favorable condition of the mine, it was considered advisable to arrange facilities for increasing the capacity to 400 tons. While it is best in some cases to adopt a distinct independent unit system where future enlargement is contemplated, in this instance the plans worked out differently. Summarized, the treatment adopted consists of coarse crushing, coarse grinding, fine grinding and cyanidation.

For coarse crushing the selection of the No. 6 size gyratory crusher was governed not so much by its capacity as by the size of the feed openings to receive the run-of-mine material, which was too coarse for a No. 5 crusher.

To accomplish the coarse grinding to best advantage, a careful comparison was made between the modern steel ball-mill—the last word in crushing and grinding—and one of its older, and, at that time better-established, competitors, the rolls. The following conclusion was reached: While it is possible that for the sized plant under consideration the cost of operating rolls might be a little cheaper, it is preferable to use ball-mills because a simpler arrangement is possible, and because the handling of ball-mills is preferred by the operator.

A marked departure was introduced for fine grinding. Instead of the long type of tube-mill, using pebbles, a mill of similar design was selected, but of much shorter length, using small cast-steel balls as grinding medium.

For cyanidation, the Dorr continuous countercurrent process was

adopted, its advantages for these conditions having been clearly demonstrated in one of the local mills.

In addition to the installation of a new hoist with gallows frame, surface plant and mill, with various shops and store houses, provision for supplying water had to be made also and, consequently, a pumping plant with necessary pipe line was installed.

Pumping Plant

The water supply is taken from a well about 4 miles from the mill. The well pit was enlarged and a 2-in. (50.8-mm.) centrifugal booster pump set down about 20 ft. (6 m.) below surface, pumping into a tank from whence a 4 by 8-in. (101.6 by 203.2-mm.) Dow triplex pump driven by a 30-hp. motor supplies a 4-in. pipe line at 400 lb. per square inch pressure and 75 gal. per minute. Immediately at the pump discharge a water relief valve set at 500 lb. per square inch is installed and beyond this is a standpipe or air cushion made of 10-in. (25.4-cm.) pipe and fittings and connected to a hydraulic air pump. Beyond the standpipe and outside of the pump house is a check valve to protect the house and contents in case of a break below the valve. The pipe line goes over rough country and lies on the surface except where it crosses Silver Creek, at which place it is buried about 3 ft. (0.9 m.) for a length of about 300 ft. (90 m.). It has expansion joints made up of four ells and three short pieces of pipe about every 500 ft. (150 m.). The tops of all important vertical bends have air-outlet valves and the bottoms have drain cocks. The four-ell expansion joints aid materially in laying the pipe over irregular country, while the resistance is small because of the low velocity of the water. The pipe line ends at two water-storage tanks having a capacity of 75,000 gal. each and located about 75 ft. (23 m.) above the surface plant. From here a 4-in. gravity line serves the mill and mine.

Mill Site

The mill site was chosen on a hill having its apex near the strike of the United Eastern vein, the top of the hill being suitable for the surface plant and the side of the hill having the necessary slope for the grinding departments. A level site for the cyanide plant was obtained by excavation, and the top of the hill was leveled off for the surface plant. The new three-compartment shaft to be sunk, known as Shaft No. 2, was located primarily, favoring conditions underground as much as possible, and the exact position of the hoist as well as that of the coarse-crushing plant and mill was subject to this location. It was of considerable importance to have the mill tailings discharged at as high an elevation as possible, on account of the topography of the country required for tailing storage,

and therefore the mill building was pushed further up the hill than it otherwise would have been.

Hoisting Plant

An Allis-Chalmers double-drum electric hoist direct-connected to a 150-hp. motor through flexible coupling and herringbone gears is installed at the opposite edge from the shaft to the north with a 75-ft. timber headframe equipped with 7-ft. sheaves. On the opposite side of the shaft from the headframe, to the south, the mine run bin is built up above a fill through which concrete walls 12 in. thick are placed 7-ft. centers at right angles to the contours of the hill. The bin is designed to discharge by gravity 100 tons through a gate near one side in the bottom onto a steel apron feeder. The ore is hoisted in two 2-ton, specially designed Kimberly-type self-dumping skips working in balance. The skips are loaded from pockets, at the various levels, having chutes swinging on vertical axes. Each skip is built integral with a cage above it which is used to hoist waste to the shaft collar in cars, as well as for men and mine supplies. The hoist is equipped with automatic accelerator and decelerator, electric overwinding device operating a solenoid brake on the motor shaft and further protected by a push button cutout at the operator's hand. The drums are mounted with clutches so that either drum may be run independently. One skip and cage together weigh 4860 lb. The starting load on the hoist under maximum conditions, *i.e.*, operating out of balance and having 2 tons of ore in the skip, 1 ton of waste in the cage and ¾ ton of cable, totals about 4¼ tons; and under ordinary conditions of operating in balance the starting load is about 2¾ tons. Speed of travel is 800 ft. per minute.

Crushing Plant

The primary crushing department consists of a No. 6 Telsmith crusher belted to a 50-hp. motor and is automatically fed by a 42-in. steel apron feeder moving 1½ ft. per minute and discharging 25 tons per hour. The ore is crushed to 3 in. and drops onto an 18-in. wide 20° inclined belt conveyor passing over a Merrick weightometer and is discharged into a 24 by 24-ft. circular wooden tank bin, having its discharge gate in the center of the bottom. This represents the ideal case for loading and discharge, giving the maximum capacity for the size of the bin; less expensive than a rectangular bin and more efficient. The bottom of the bin is built of 4-in. material while the staves consist of 3-in. material, all Oregon pine lumber. The hoisting and primary crushing is intended to be done in one shift.

Mill

The coarse-grinding department consists of two No. 64½ Marcy mills each direct-connected to 100-hp. Allis-Chalmers motors through

flexible couplings and herringbone gears; automatically fed at the rate of 8½ tons per hour by an 18-in. steel apron conveyor traveling at the rate of 1½ ft. per minute, taking the crushed ore from the bottom of the circular bin, its discharge being split for each ball mill. Each Marcy mill operates in closed circuit with a duplex Callow screen, the oversize of which is returned to the Marcy mill by an 18-in. belt and bucket elevator and the undersize (−30-mesh) goes to a combined distributer and sampler. The feed to the Callow screens is arranged so that either Marcy mill may work with either screen. Before deciding on Callow screens for this separation, Dorr classifiers were considered, the idea being that they were more economical in operation, and that the special elevator for returning the +30-mesh might be eliminated, but since up to that time a Dorr classifier had not been proved to be satisfactory on material coarser than 48-mesh, preference was given to the Callow screen.

The work intended for one ball-mill operating in closed circuit as described consists of grinding 200 tons of ore that has passed a 3-in. ring to a product passing a 30-mesh screen per 24 hr., the mill being loaded with from 7000 to 8000 lb. of 5-in. balls. While one ball-mill apparently would have been of sufficient capacity for the initial mill tonnage required, it was deemed advisable to install a second machine, having in mind the possible increase in tonnage which soon may have to be met, and also realizing the necessity of a standby machine to secure continuous operation of the plant. The Marcy mills are fitted with specially designed feed scoops, so that the wet rejects from the Callow screens are taken in at the periphery while the dry ore from the feeder goes directly into the center of the scoop.

The fine-grinding department is composed of three Allis-Chalmers tube-mills, 5 ft. in diameter by 6 ft. long, each direct-connected to 75-hp. motors through flexible couplings and herringbone gears, operating in closed circuit with a Dorr duplex classifier. The feed comes from the combined distributer and sampler to the Dorr classifier, the coarse discharge of which is taken into the tube mill by a 42-in. scoop. The Dorr classifiers overflow into a launder to a Callow 8-ft. sloughing-off tank where additional settling is expected to take place. These tube-mills, or ball-peb mills as they are designated by the manufacturer, are built to use ⅞-in. diameter cast-steel balls instead of pebbles as grinding medium. Like the ball-mills, they are lined with steel. The work intended for one ball-peb mill operating in closed circuit consists of grinding 133 tons of 30-mesh feed so that 85 per cent. of the discharge will pass through a 200-mesh screen, using a charge of 13,000 lb. of ⅞-in. diameter ball-pebs. It will be noticed that in the fine-grinding department the same idea referring to future increase in tonnage as well as standbys again was observed. In adopting these extremely short tube mills for fine grinding preparatory to cyanidation, considerable hesitancy was displayed, since, excepting some information on dry work in cement plants, no records

of operating results were obtainable. But it is only fair to say that the manufacturer, as was also true in the case of the Marcy ball-mills, was willing to substantiate his claim with the requested tangible operating guarantees. The results obtained at this writing are not absolutely conclusive, but it appears that the work of both types of machines will be well within their respective expectations.

Continuous countercurrent decantation is the cyanide process used, in which the pulp continuously flows toward the lower end while the clear solution continuously flows toward the upper end. The cyanide solution is entered at the Marcy mills and most of the values will be dissolved before reaching the first cyanide tank. The cyanide plant has five Dorr thickener tanks 40 by 12 ft. and four Dorr agitators 24 by 14 ft., arranged in the following order: thickener, three agitators, thickener, agitator, three thickeners. Each thickener has a Campbell and Kelly diaphragm pump located above the tank to pump the pulp into the tank following. The first thickener is taking the overflow from the Callow sloughing-off tank, the pulp discharged is pumped into the first agitator, and the clear solution overflow goes by gravity through a solution meter and thence into a 20 by 10-ft. press solution tank. The pulp passes through the first three agitators and into the second thickener by gravity, thence by pump to the fourth agitator, thence by gravity to the third thickener, and thence by pump to the fourth and fifth thickeners and tailings launder respectively. The second thickener overflow is returned to the mill-solution supply tank at the head of the mill via a priming tank and centrifugal pump. The third thickener overflow is returned to the first agitator by similar means. The fourth thickener overflow may go by gravity to the third thickener or at option may be pumped to the fourth agitator. The fifth thickener overflow goes by gravity to the fourth thickener. Barren solution is added to the launder from No. 4 thickener to No. 3 thickener and fresh water to the launder from No. 5 thickener to No. 4 thickener. The three centrifugal pumps handling the clear solution are each connected to a fourth pump acting as standby. Each pump is direct-connected, motor-driven, and equipped with automatic float switch at the priming tank to shut off the motor should the priming tank be drained. A small compressor is installed to supply air to the agitators at 20 lb. pressure.

The solution from the first thickener after entering the press solution tank is pumped by a centrifugal pump through a 3½ by 3½-ft., 28-frame Merrill clarifying press, the clarified solution going by gravity to a 20 by 10-ft. gold tank. From here a 7 by 8-in. Platt Iron Works pump sends the pregnant solution through two Merrill 36-in., 32-frame precipitation presses, zinc dust having been added by means of a feeder and emulsifier to the pipe from the gold tank to the triplex pump. Duplicate triplex and centrifugal standby pumps are installed.

Barren solution from the precipitation presses goes to a sump from whence it is pumped to the mill-solution supply tank. Refining of the precipitate is accomplished with a two-muffle Case roasting furnace and a Case tilting-crucible furnace.

The tank-settling area for the thickeners and the capacity of the agitators is calculated for treating 240 tons per 24 hr., but the height of the thickeners has purposely been increased by 2 ft., which will allow for the insertion of a false floor or deck in each tank, which with an additional set of rabble arms on the shafts, will bring the capacity of the thickeners up to 400 tons. Thus if the anticipated increase in production from 200 to 400 tons should have to be met, it will simply require the installation of the necessary agitators, a comparatively small item.

In addition, auxiliaries such as machine shop, blacksmith shop, warehouse and transformer house are built. An incline tramway is installed to haul supplies and construction material for the mine and mill, from the wagon road below.

The buildings are all timber framed and covered with corrugated iron, except the refinery, which is constructed of hollow concrete block walls, steel roof trusses and corrugated iron roof covering. The grinding and cyanide departments have concrete floors sloping ¼-in. per foot where possible and all draining into a sump on the lowest floor.

In submitting this description, no particular stress was laid on describing detail, but the several drawings attached, especially the flow sheet, should give additional information.

A comprehensive idea of the total cost of the installation as well as of the individual departments can be had from the attached cost distribution. Taking, for the purpose of comparison with the cost of other cyanide plants, what is generally understood to be part of a milling plant, such as crushing plant, mill proper, and refinery, shops, offices, store houses, assay office, and inclined railroad for distributing purposes, and allowing liberally for extending the cyanide plant to 400 tons capacity, the cost of the plant per ton of ore treated amounts to $520. This, in view of the fact that the mine is located 28 miles from the nearest railroad station and all the material had to be transported by motor truck or wagon, and that the purchasing orders were placed at a time when the various machines and materials were averaging at least 15 per cent. above normal, is a very low figure.

The compactness of the plant, including the principal departments, such as crushing, milling, and refining, is shown by comparison with two other cyanide plants recently designed by the writer; one 500-ton plant occupies 112 sq. ft. and one 350-ton plant, 110 sq. ft. per ton of ore treated, while the United Eastern installation on a basis of 400 tons covers an area of only 70 sq. ft. per ton of ore capacity. The cost per ton treated of the 500-ton mill, with the main mill building being constructed

of steel, was $930, while the 350-ton plant of identical construction as the United Eastern cost $681 per ton of ore treated. Both of these mills are situated on branch line railroads and were built at a time when prices of material were normal.

Detailed Description of Items Numbered on Fig. 1.

Surface Plant

1. Shaft collar, three-compartment shaft, 5 ft. 0 in. by 5 ft. 0 in. in clear.
2. Headframe, 32 ft. 0 in. by 36 ft. 6 in. base, 76 ft. 0 in. from shaft collar to center of sheaves.
3. Hoisting sheaves, 7 ft. 0 in. diameter, 4 7/16-in. bore, 1-in. cable.
4. Sheave for manway, 2 ft. 6 in. diameter, 2 15/16-in. bore, 1/2-in. cable.
5. Skip dumping frame.
6. Allis-Chalmers double-drum electric hoist with parallel motion post brakes, 150-hp. motor direct-connected through herringbone gears, rope speed 800 ft. per minute.
7. Mine compressor, Ingersoll-Rand, 19 by 12 by 16-in. belt-driven, furnishes 888 cu. ft. of free air at 100-lb. pressure.
8. 150-hp. Allis-Chalmers motor, 695 r.p.m., 24 by 20-in. pulley.
9. Hoist house.
10. Three concrete walls 12 in. thick supporting bin.
11. Concrete wall, 14-in. top, batter 1 in. per foot, supporting bin and is retaining wall above crusher floor.
12. Coarse ore bin 16 ft. 6 in. by 16 ft. 6 in. by 19 ft. 6 in. deep, to discharge 100 tons gravity.

Coarse-crushing Department

13. 42-in. steel apron feeder driven by 3-hp. motor through five trains of gears at 1 1/2 ft. per minute to discharge 25 tons per hour.
14. No. 6 Telsmith gyratory crusher, 46 by 12-in. pulley at 320 r.p.m.
15. 50-hp. Allis-Chalmers motor, 8 by 12-in. pulley, 860 r.p.m.
16. Crusher house.
17. 18-in. inclined troughing conveyor troughing rolls 5 ft. 0 in. centers, return rolls 10 ft. 0 in. centers, weighted takeup.
18. Merrick weightometer.
19. 10-hp. Allis-Chalmers motor 9 by 7-in. pulley 575 r.p.m.

Coarse- and Fine-grinding Department

20. Mill bin 24 ft. diameter by 24 ft. high, wooden tank 3-in. sides, 4-in. bottom, to discharge 400 tons by gravity.
21. Mill building.
22. 18-in. steel apron feeder, to discharge 8 1/2 tons per hour at 1 1/2 ft. per minute travel.
23. 3-hp. motor driving feeder through five trains of spur gears.
24. Chute with deflector to throw ore into either or both Marcy mills.
25. Two No. 64 1/2 Marcy mills having special side opening scoops, 25 r.p.m.
26. 100-hp. motors, 435 r.p.m., direct-connected to Marcy mills through herringbone gears.

27. Launder from Marcy mills to Callow screens, slope 1 in. per foot.

28. 4-in. pipe cross-connecting Marcy mills and Callow screens.

29. Two Callow duplex traveling belt screens.

30. Chute taking screen oversize to slime elevator.

31. Slime elevator, 18-in. belt, 300 ft. per minute, two rows of 8 by 5 by 3½-in style "B" malleable buckets, 6-in. centers.

32. Chute from slime elevator to Marcy mill feed box, slope 40°.

33. Launder from screen undersize to distributer.

34. Combined mechanical distributer and sampler.

35. 4-in. pipes from distributer to classifiers, slope 1 in. per foot.

36. Three Dorr duplex classifiers in closed circuit with ball-peb mills.

37. Three 5 by 6-ft. Allis-Chalmers ball-peb mills with 42-in. scoops, 28 r.p.m.

38. Three 75-hp. Allis-Chalmers motors, 435 r.p.m., direct-connected to ball-peb mills through herringbone gears.

39. 4-in. pipe from ball-peb mills to classifiers.

40. 4-in. pipe from classifiers to Callow tank.

41. 25-hp. Allis-Chalmers motor, 860 r.p.m., 12 by 8-in. pulley, driving countershaft which drives slime elevator, Callow screens, distributer and Dorr classifiers.

42. 15-hp. Allis-Chalmers motor, 860 r.p.m., 10 by 8-in. pulley driving cyanide department countershaft thence to main line shaft driving five thickeners, four agitators and five diaphragm pumps.

Cyanide Department

43. Launder from classifiers to Callow tank, slope 1 in. per foot.

44. 8-ft. Callow sloughing-off tank.

45. 5 by 6-ft. slope bottom tank to take Callow spigot discharge.

46. 1-in. direct-connected centrifugal slime pump to pump from 5 by 6 tank to classifiers.

47. Launder from Callow tank to No. 1 thickener, slope 1 in. per foot.

48. No. 1 thickener tank, 40 by 12 ft., Dorr machinery, 1/10 r.p.m. of arms, settling area 1227 sq. ft., capacity of tank 12,810 cu. ft. = 96,000 gal. = 480 tons.

49. 4-in. pipe carrying pulp from No. 1 thickener to No. 1 diaphragm pump.

50. 4-in. pipe carrying solution from No. 1 thickener to press-solution tank.

51. No. 1 diaphragm pump.

52. Launder from No. 1 diaphragm pump to No. 1 agitator.

53. No. 1 agitator tank 24 by 14 ft., capacity 5225 cu. ft. = 39,100 gal. = 196 tons, Dorr machinery, 2 to 3 r.p.m. of arms.

54. Launder from No. 1 agitator to No. 2 agitator, slope 2 in. per foot.

55. No. 2 agitator same as No. 1 agitator.

56. Launder from No. 2 agitator to No. 3 agitator, slope 2 in. per foot.

57. No. 3 agitator same as No. 1 agitator.

58. Launder from No. 3 agitator to No. 2 thickener, slope 2 in. per foot.

59. No. 2 thickener same as No. 1 thickener.

60. 4-in. pipe carrying pulp from No. 2 thickener to No. 2 diaphragm pump.

61. 4-in. pipe carrying solution from No. 2 thickener to sump tank.

62. No. 2 thickener overflow sump tank 10 by 6 ft., capacity 381 cu. ft. = 2850 gal. = 11.9 tons, holding capacity 18 min., equipped with automatic electric float switch controlling pump motor.

63. 3-in. pipe from sump tank 62 to pump 64.

64. 2½-in. Krogh centrifugal pump direct-connected to 7½-hp. G.E. motor, 1740 r.p.m.

65. 3-in. pipe from pump 64 to mill-solution tank.

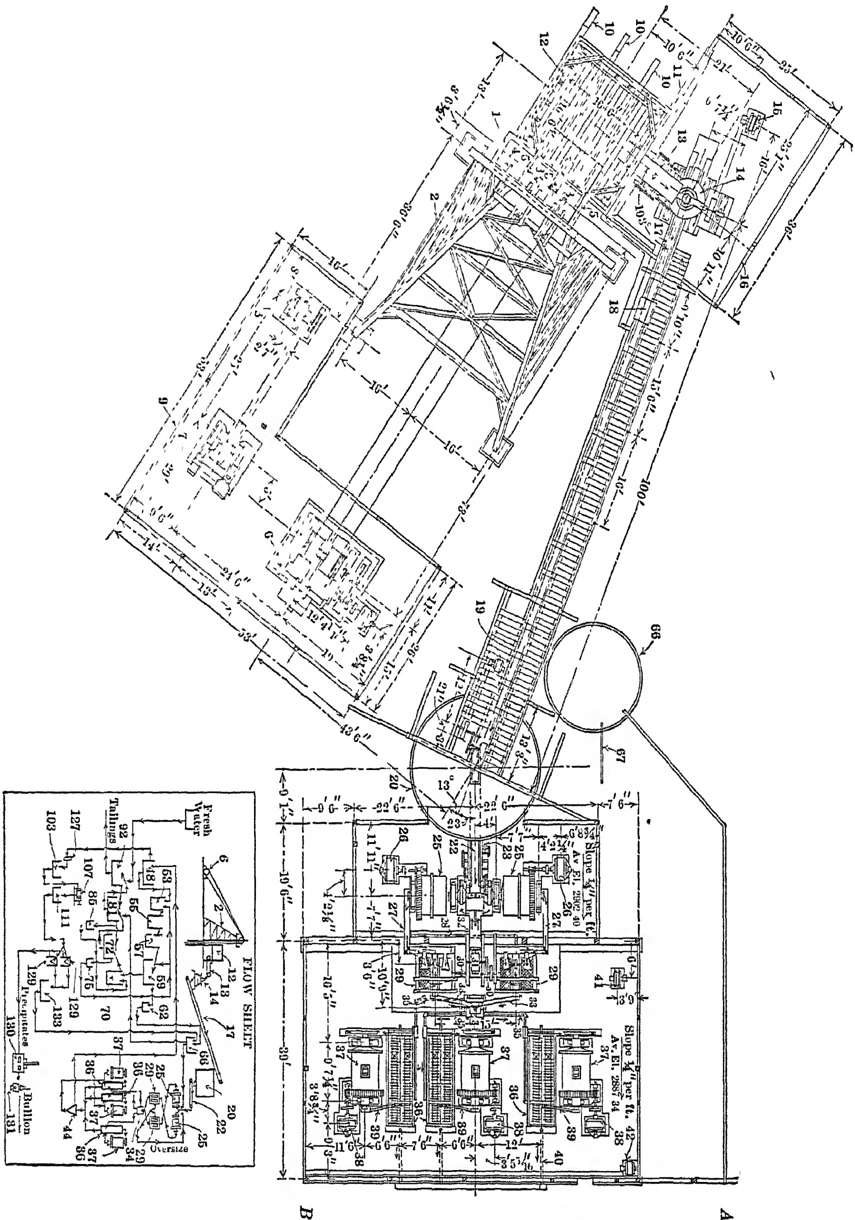
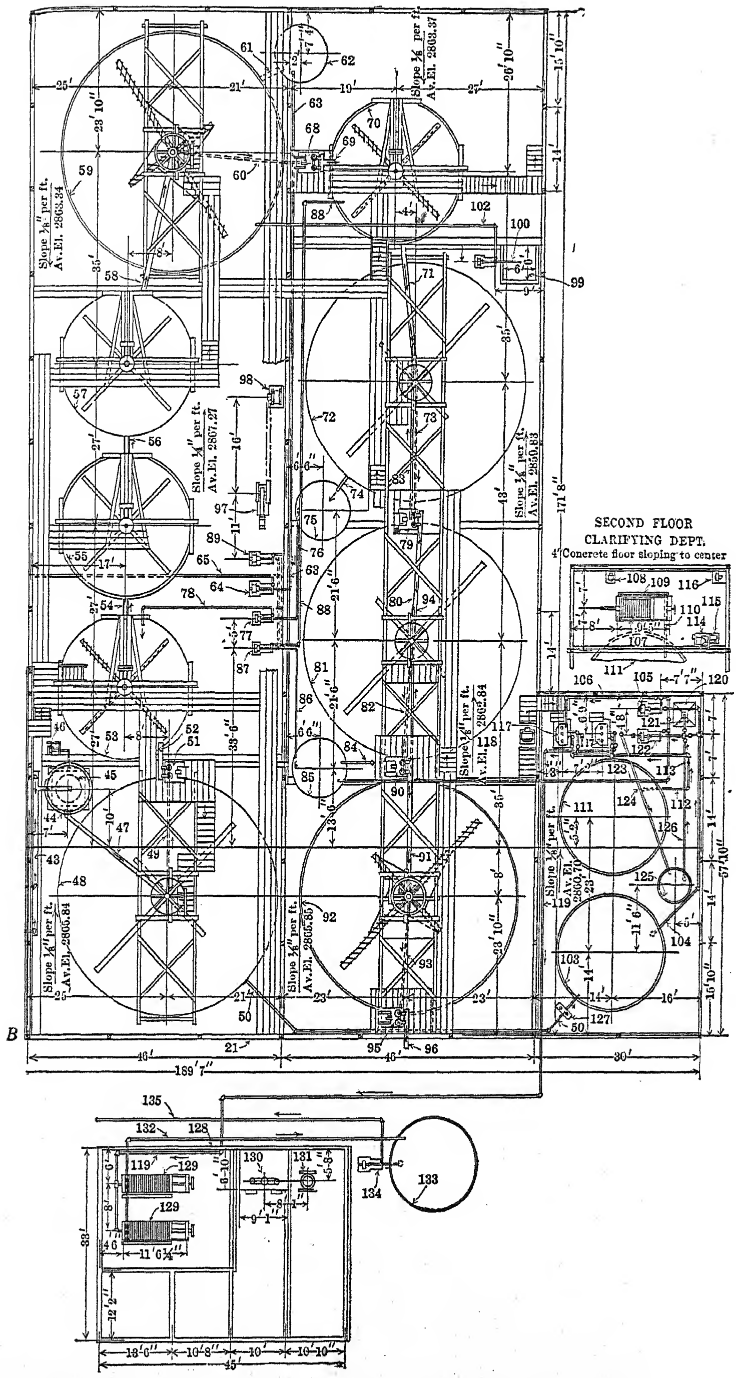


FIG. 1.—GENERAL ARRANGEMENT OF 200-TON CYANIDE

NOTE.—The two sections of the cut



MILLING PLANT OF THE UNITED EASTERN MINING O.
fit together on the line *AB*.

66. Mill-solution tank 18 by 16 ft., capacity 3700 cu. ft. = 27,700 gal. = 116 tons.
67. 3-in. pipe from mill-solution tank to mill.
68. No. 2 diaphragm pump.
69. Launder from No. 2 diaphragm pump to No. 4 agitator.
70. No. 4 agitator same as No. 1 agitator.
71. Launder from No. 4 agitator to No. 3 thickener, slope 2 in. per foot.
72 No. 3 thickener same as No. 1 thickener.
73. 4-in. pipe carrying pulp from No. 3 thickener to No. 3 diaphragm pump.
74. 4-in. pipe carrying solution from No. 3 thickener to sump tank.
75. No. 3 thickener overflow sump tank same as 62.
76. 3-in. pipe from sump tank 75 to pump 77.
77. 2½-in. Krogh centrifugal pump direct-connected to 3-hp. G.E. motor, 1720 r.p.m.
78. 3-in. pipe from pump 77 to No. 1 agitator.
79. No. 3 diaphragm pump.
80. Launder from No. 3 diaphragm pump to No. 4 thickener, slope 1 in. per foot.
81. No. 4 thickener same as No. 1 thickener.
82. 4-in. pipe carrying pulp from No. 4 thickener to No. 4 diaphragm pump.
83. 4-in. pipe carrying solution from No. 4 thickener to launder 71, slope 3⁄16 in. per foot., has gate valve.
84. 4-in. pipe carrying solution from No. 4 thickener to sump tank 85, has gate valve.
85. No. 4 thickener overflow sump tank, same as 62.
86. 3-in pipe from sump tank 85 to pump 87.
87. 2½-in. Krogh centrifugal pump direct-connected to 2-hp. G.E. motor, 1700 r.p.m.
88. 3-in. pipe from pump 87 to No. 4 agitator.
89. 2½-in. Krogh centrifugal pump direct-connected to 7½-hp. G.E. motor, 1740 r.p m. used as standby, interconnected to pumps 64, 77 and 87.
90. No. 4 diaphragm pump.
91. Launder from No. 4 diaphragm pump to No. 5 thickener, slope 1 in. per foot.
92. No. 5 thickener same as No. 1 thickener.
93. 4-in. pipe carrying pulp from No. 5 thickener to No. 5 diaphragm pump.
94. 4-in. pipe carrying solution from No. 5 thickener to launder 80, slope 3⁄16 in. per foot.
95. No. 5 diaphragm pump.
96. Tailings launder to tailings pond.
97. Ingersoll-Rand compressor, 9 by 8, 17 b.hp.
98. 20-hp. G.E. motor, 12 by 8½-in. pulley, 1160 r.p.m.
99. Cyanide department floor sump, 6 ft. 0 in. by 6 ft. 0 in. by 6 ft. 0 in.
100. 2½-in. pipe with foot valve from sump to pump.
101. 2-in. Krogh centrifugal pump direct-connected to 2-hp. G.E. motor, 1700 r.p.m.
102. 2½-in. pipe from pump 101 to No. 2 thickener.

Clarifying Department

103. Press-solution tank, 20 by 10 ft., capacity 2800 cu. ft. = 20,950 gal. = 87.5 tons, holding capacity 2½ hr.
104. 4-in. pipe carrying solution from press-solution tank to centrifugal pump 105.
105. 2½-in. Krogh centrifugal pump direct-connected to 7½-hp. G.E. motor, 1740 r.p.m., pumps solution through clarifying press.

106. 3-in. pipe from centrifugal pump 105 to clarifying press.

107. $3\frac{1}{2}$ by $3\frac{1}{2}$-ft. 28-frame Merrill clarifying press.

108. 1-hp. G.E. motor, 1130 r.p.m., $4\frac{1}{2}$ by $2\frac{1}{2}$-in. pulley driving clarifying press through countershaft.

109. Launder taking clear solution discharge from clarifying press.

110. 4-in. pipe from launder 109 to gold tank.

111. Gold tank 20 by 10 ft., capacity 2800 cu. ft. = 20,950 gal. = 87.5 tons, holding capacity $1\frac{3}{4}$ hr.

112. 3-in. pipe from gold tank to triplex pumps.

113. Entrance of zinc dust from feeder and emulsifier through $2\frac{1}{2}$-in. pipe.

114. Zinc-dust feeder.

115. Zinc-dust emulsifier.

116. 1-hp. G.E. motor, $4\frac{1}{2}$ by $2\frac{1}{2}$-in. pulley, 1130 r.p.m., driving 114 and 115 through countershaft.

117. Two 7 by 8-in. Platt Iron Works triplex pumps, 30 by $8\frac{1}{2}$-in. Tel pulleys, 260 r.p.m., 200 gal. per minute, one pump to act as standby.

118. 15-hp. G.E. motor, 8 by $5\frac{3}{4}$-in. pulley, 1160 r.p.m., driving triplex pumps through countershaft.

119. 4-in. pipe carrying solution with zinc dust added from triplex pump to precipitation presses in refinery building.

120. Clarifying-department floor sump.

121. $2\frac{1}{2}$-in. pipe with foot valve, floor sump to pump 122.

122. $2\frac{1}{2}$-in. Krogh centrifugal pump direct-connected to $7\frac{1}{2}$-hp. G.E. motor, 1740 r.p.m., pumping from floor sump and tank 125 to tank 85, also connected to act as standby to pump 105.

123. 3-in. pipe from pump 122 to tank 85.

124. 4-in. pipe draining clarifying press floor into sump tank 125.

125. Sluicing water sump tank 6 by 8 ft., capacity 1600 gal.

126. 3-in. pipe from tank 125 to pump 122.

127. Meter for measuring pregnant solution.

Refinery

128. Refinery building, concrete block walls, steel roof.

129. Two Merrill 36-in. 32-frame precipitation presses.

130. Case roasting furnace, two 11 by 22-in. muffles.

131. Case tilting crucible furnace.

132. 3-in. pipe from precipitate presses to barren-solution tank.

133. Barren-solution sump tank 16 by 16 ft.

134. $2\frac{1}{2}$-in. Krogh centrifugal pump, direct-connected to $7\frac{1}{2}$-hp. G.E. motor, 1740 r.p.m.

135. 4-in. pipe from barren-solution to mill-solution tank.

UNITED EASTERN MINING CO.
STATEMENT OF COST OF CONSTRUCTION OF MINING AND MILLING PLANT AS AT JAN. 31, 1917

Mining and Milling Plant—Index and Summary

Table No.	Account Title	Labor	Material	Power	Miscellaneous	Total
	Mine:					
1	Headframe	$1,687.35	$2,480.00	....	$33.75	$4,201.10
2	Compresser and Hoist House	3,904.24	19,730.42	....	....	23,634.66
3	Timber Framing Shed	340.39	835.80	....	.. ..	1,176.19
4	Blacksmith Shop	211.57	1,644.89	....	....	1,856.46
5	Change House	699.42	1,090.84	....	1.00	1,791.26
6	Foreman's Office	88.88	142.75	....	....	231.64
7	Timber Yard	408.84	428.59	....	....	837.43
7	Change Room, No. 1 Shaft	79.00	118.98	....	....	197.98
7	Blacksmith Shop, No. 1 Shaft	12.00	14.12	....	77.19	103.31
7	Hoist House and Equipment, No. 1 Shaft	351.86	4,300.40	....	....	4,652.26
7	Powder Magazine	269.62	250.80	....	....	520.42
	Mill:					
8	Mill Proper	32,211.08	90,328.04	$135.81	10,864.16	133,539.09
9	Crushing Plant	2,456.50	9,504.81	....	14.06	11,975.37
10	Coarse Ore Bins	953.97	962.30	....	....	1,916.27
11	Refinery	2,093.52	3,695.61	....	....	5,789.13
7	Lime House	146.32	126.22	....	....	272.54
	Miscellaneous:					
12	Machine Shop	815.02	7,407.92			8,222.94
13	Storehouse	824.74	2,266.60	......	....	3,091.34
14	Transformer House	517.64	4,109.53	......	....	4,627.17
15	Assay Office	457.90	1,711.77	......	....	2,169.67
7	Oil House	35.50	101.61	....	....	137.11
16	Inclined Tramway	224.02	880.84	....	....	1,104.86
3	Garage, No. 1 Shaft	38.00	2.35	....	97.25	137.60
7	General Office	1,215.11	5,122.99	....	120.00	6,458.10
7	Cottages	712.05	2,477.05	....	....	3,189.10
7	Blue-print House	28.00	59.58	....	....	87.58
17	Water System	2,197.34	18,780.23	....	3,321.31	24,298.88
7	Power Lines	610.99	432.72	....	6.94	1,050.65
7	Local Telephone System	87.69	226.74	....	....	314.43
7	New Roads	840.40	43.38	....	....	883.78
	Total Mining and Milling Plant	$54,516.96	$179,277.89	$135.81	$14,535.66	$248,468.32

TABLE 1.—*Gallows Frame Construction*

	Labor	Material	Miscellaneous	Total
Excavation	$387.84	$33.25	......	$421.09
Concrete	72.12	42.17	......	114.29
Machinery, f.o.b. Oatman	....	331.07	......	331 07
Machinery, Erection	8.38	....	......	8.38
Building Lumber	....	1,760.09	......	1,760 09
Lumber Framing and Erection	1,107.41	248.32	$33.75	1,389.48
Electric Wiring, f.o.b. Oatman	....	65.10	......	65.10
Electric Wiring, Erection	51.60	....	......	51.60
Engineering, Field	25.00	....	......	25.00
Painting	35.00	....	......	35.00
Total Gallows Frame Construction	$1,687.35	$2,480.00	$33.75	$4,201.10

TABLE 2.—*Compressor and Hoist House*

	Labor	Material	Total
Excavation	$965.21	$785.95	$1,751.16
Concrete	16 25	60.22	76.47
Hoist:			
Machinery, f.o.b. Oatman	....	8,434.02	8,434.02
Machinery, Erection	245.00	96.48	341.48
Compressor:			
Machinery, f.o.b. Oatman	....	3,991.21	3,991.21
Machinery, Erection	283.07	67.14	350.21
Building Lumber	....	572.17	572.17
Lumber Framing and Erection	568.51	80.21	648.72
Building Covering in Place	47.50	324.02	371.52
Doors and Windows in Place	6.50	2.57	9.07
Piping, f.o b. Oatman	....	108.79	108.79
Electric Wiring, f.o.b. Oatman	....	1,505.60	1,505.60
Electric Wiring, Erection	295.93	....	295.93
Engineering, Field	181.65	....	181.65
Painting	1.88	22.72	24.60
Installing Equipment	1 292.74	3,679.32	4,972.06
Total Compressor and Hoist House	$3,904.24	$19,730.42	$23,634.66

TABLE 3.—*Surface Plant (Other Than Mill)*

	Labor	Material	Miscellaneous	Total
Garage construction:				
At No. 1 Shaft	$38.00	$2.35	$97.25	$137.60
Timber Framing Shed Construction:				
Building Complete	161.81	384.79	......	546.60
Equipment Installed Complete	178.58	451.01	......	629.59
Total Timber Framing Shed Construction	$340.39	$835.80	......	$1,176.19

TABLE 4.—*Blacksmith Shop*

	Labor	Material	Total
Machinery, f.o b Oatman	....	$1,362 62	$1,362.62
Machinery, Erection	$85.76	37.43	123.19
Building Lumber	....	80.49	80.49
Lumber Framing and Erection	78.68	4.54	83.22
Building Covering in Place	....	78.54	78.54
Doors and Windows in Place	0.75	12.00	12.75
Piping, f.o.b. Oatman	....	54.17	54.17
Piping, Erection	12.30	8.86	21.16
Electric Wiring. f o.b Oatman	....	6.24	6.24
Electric Wiring, Erection	19.50	....	19.50
Engineering, Field	6.45	....	6.45
Painting	8.13	....	8.13
Total Blacksmith Shop	$211.57	$1,644.89	$1,856.46

TABLE 5.—*Change House*

	Labor	Material	Miscellaneous	Total
Excavation	$224.45	$6.81		$231.26
Concrete	74.88	111.46	$16.00	202.34
Machinery, Erection	15.76	12.93	....	28.69
Building Lumber	....	213.56	....	213.56
Lumber Framing and Erection	127.49	11.10	....	138.59
Building Covering in Place	0.75	205.22	....	205.97
Doors and Windows in Place	44.75	44.28	....	89.03
Piping, f o.b. Oatman	....	118.41	....	118.41
Piping, Erection	20.94	....	....	20.94
Electric Wiring, f.o.b. Oatman	....	5.57	....	5.57
Electric Wiring, Erection	2.98	....	....	2.98
Engineering, Field	13.10	....	....	13.10
Furniture and Fixtures	124.94	327.20	15.00[1]	437.14
Painting	49.38	34.30	....	83.68
Total Change House	$699.42	$1,090.84	$1.00	$1,791.26

[1] Credit.

TABLE 6.—*Foreman's Office*

	Labor	Material	Total
Concrete	$2.00	$2.84	$4.84
Building Lumber	......	74.09	74.09
Lumber Framing and Erection	54.13	2.80	56.93
Building Covering in Place	1.50	29.98	31.48
Doors and Windows in Place	1.50	3.60	5.10
Electric Wiring, f.o.b. Oatman	......	2.50	2.50
Furniture and Fixtures	21.00	26.95	47.95
Painting	8.75	....	8.75
Total Foreman's Office	$88.88	$142.76	$231.64

TABLE 7.—*Surface Plant (Other Than Mill)*

	Labor	Material	Miscellaneous	Total
Timber Yard Construction:				
Timber Yard including Skids	$408.84	$428.59	....	$837.43
General Office Construction:				
Building	$1,215 11	$2,848 00	$120.00	$4,183.11
Equipment	....	2,274 99	....	2,274.99
Total General Office	$1,215.11	$5,122 99	$120 00	$6,458.10
Cottages, Construction:				
No. 1 Building	$643.05	$1,424.79	....	$2,067.84
No. 1 Furnishings	....	451.98	....	451.98
No. 2 Cottage	69.00	600.28	....	669.28
Total Cottages, Construction	$712.05	$2,477.05	....	$3,189 10
Blue Print House, Construction:				
Building and Equipment	$28 00	$59.58	....	$87.58
Oil House Construction	35.50	101.61	....	137.11
Lime House Construction	146.32	126.22	....	272.54
No. 1 Shaft Change Room	79.00	118.98	....	197.98
No. 1 Shaft Blacksmith Shop	12.00	14.12	$77.19	103.31
New Powder Magazine	269.62	250.80	....	520.42
No. 1 Shaft Hoist House and Equipment	351.86	4,300.40	....	4,652.26
Power Lines	610.99	432 72	6.94	1,050 65
Local Telephone System	87.69	226.74	....	314.43
New Roads	840.40	43.38	....	883.78

TABLE 8.—*Main Mill Construction*

	Labor	Material	Power	Miscellaneous	Total
Excavation	$10,897.04	$2,203.52	....	....	$13,100.56
Concrete	5,473.74	4,411.18	$21.54	$945.85	10,852.31
Machinery, f o.b. Oatman[1]	....	57,487.02	....	....	57,487 02
Machinery, Erection	4,022.18	862 36	114 27	390.75	5,389.56
Building Lumber	....	7,411.87	....	....	7,411.87
Lumber Framing and Erection	5,205.89	538.02	....	420.96	6,164.87
Building Covering in Place	821 50	2,302.77	....	....	3,124.27
Doors and Windows in Place	183.06	75.16	....	....	258 22
Wood Tanks, f.o.b. Oatman	....	7,811 06	....	....	7,811 06
Wood Tanks, Erection	939.27	122.80	....	3 62	1,065.69
Piping, f.o.b. Oatman	....	2,864.93	....	....	2,864.93
Piping, Erection	1,329.63	....	....	....	1,329 63
Electric Wiring, f o.b Oatman	....	2,906.89	....	....	2,906 89
Electric Wiring, Erection	1,483.04	....	....	....	1,483 04
Belting in Place	18.06	722 22	....	....	740 28
Launder Lumber	....	71.57	....	....	71 57
Launders, Erection	412.14	22.87	....	....	435 01
Engineering, Los Angeles Office	....	....	....	9,050.99	9,050 99
Engineering, Field	749.05	182.80	....	51.99	983.84
Tailings Dump and Fences	330.87	24.89	....	....	355 76
Furniture and Fixtures	6.50	51.50	....	....	58.00
Painting	221.87	132 30	....	....	354.17
Small Tools and Equipment	117.24	122.31	....	....	239.55
Total Mill Construction	$32,211.08	$90,328.04	$135.81	$10,864.16	$133,539.09

[1] See note under refinery, Table 11.

TABLE 9.—*Crushing Plant Construction*

	Labor	Material	Miscellaneous	Total
Excavation	$502.00	$333 25	......	$835.25
Concrete	251.10	351 68	......	602.78
Machinery, f.o.b. Oatman	....	6,323 73	......	6,323 73
Machinery, Erection	671.20	103.27	......	774.47
Building Lumber	....	1,208.48	$14 06	1,222.34
Lumber Framing and Erection	704.20	77.82	......	782.02
Building Covering in Place	4.00	325.86	......	329.86
Doors and Windows in Place	....	19.74[1]	......	19.74[1]
Electric Wiring, f.o.b. Oatman	....	184.46	......	184.46
Electric Wiring, Erection	118.53	....	......	118.53
Belting in Place	....	586.82	......	586.82
Engineering, Field	124.85	....	......	124.85
Painting	80.62	29.18	......	109.80
Total Crushing Plant Construction	$2,456.50	$9,504.81	$14.06	$11,975.37

[1] Credit.

TABLE 10.—*Coarse Ore Bins*

	Labor	Material	Total
Excavation	$44.50	$144.75	$189.25
Concrete	520.96	61.88	582.84
Building Lumber	....	741.63	741.63
Lumber Framing and Erection	368.51	14.04	382.55
Engineering, Field	20.00	....	20.00
Total Coarse Ore Bins	$953.97	$962.30	$1,916.27

TABLE 11.—*Refinery*

	Labor	Material	Total
Plastering	$18.62	....	$18.62
Excavation	149.75	....	149.75
Concrete	808.06	$498.22	1,306.28
Machinery, f.o.b. Oatman	....	1,439.14	1,439.14
Machinery, Erection	213.24	90.73	303.97
Building Lumber, f.o.b. Oatman	....	68.06	68.06
Lumber Framing and Erection	358.20	5.50	363.70
Building Covering in Place, Includes Steel Trusses	62.00	1,007.22	1,069.22
Doors and Windows in Place	141.75	147.76	289.51
Tank, f.o.b. Oatman	....	53.35	53.35
Piping, f.o.b. Oatman	....	219.14	219.14
Piping, Erection	9.56	....	9.56
Electric Wiring, f.o.b. Oatman	....	31.75	31.75
Electric Wiring, Erection	46.62	....	46.62
Engineering, Field	63.10	....	63.10
Furniture and Fixtures	3.37	109.58	112.95
Painting	68.13	5.96	74.09
Concrete Blocks	151.12	12.00	163.12
Small Tools and Equipment	....	7.20	7.20
Total Refinery	$2,093.52	$3,695.61	$5,789.13

Precipitation presses were not charged in this account. The Merrill contract did not specify separate prices, and two precipitation presses and one clarification press, and zinc feeder, were charged to mill. The charge was:

Three presses and zinc feeder	$8,450.00
Freight	439 20
Hauling	126 00
Total	$9,015 20

Table 12.—*Machine Shop*

	Labor	Material	Total
Excavation	$25.50	....	$25.50
Concrete	....	$35.56	35.56
Machinery, f.o.b. Oatman	....	6,473 94	6,473.94
Machinery, Erection	292.69	37.10	329.79
Building Lumber	....	483 05	483.05
Lumber Framing and Erection	362.85	48.65	411.50
Building Covering in Place	....	159.17	159.17
Doors and Windows in Place	18.33	68.47	86.80
Electric Wiring, f.o.b. Oatman	....	44.34	44.34
Electric Wiring, Erection	46.68	....	46.68
Engineering, Field	13.10	....	13.10
Furniture and Fixtures	9.00	....	9.00
Painting	46.87	29 76	76.63
Small Bench Tools	....	27.88	27.88
Total Machine Shop	$815.02	$7,407.92	$8,222.94

Table 13.—*Storehouse Construction*

	Labor	Material	Total
Excavation	$199.48	$1.40	$200.88
Concrete	....	13.31	13.31
Building Lumber	....	1,389.64	1,389.64
Lumber Framing and Erection	456.11	67.69	523.80
Building Covering in Place	....	223.89	223.89
Doors and Windows in Place	85.75	120.96	206.71
Electric Wiring, f.o.b. Oatman	....	20.42	20.42
Electric Wiring, Erection	19.25	....	19.25
Engineering, Field	6.65	....	6.65
Furniture and Fixtures	30.00	429.29	459.29
Painting	27.50	....	27.50
Total Storehouse Construction	$824.74	$2,266.60	$3,091.34

TABLE 14.—*Transformer House and Equipment*

	Labor	Material	Total
Excavation	$148.05	....	$148 06
Concrete	2.00	....	2 00
Machinery, f.o b. Oatman	....	$3,327.77	3,327.77
Machinery, Erection	51.12	22.40	73.52
Building Lumber	....	174.31	174.31
Lumber Framing and Erection	40.25	....	40.25
Building Covering in Place	7.50	92.69	100.19
Electric Wiring, f.o.b. Oatman	......	475.83	475.83
Electric Wiring, Erection	181.21	....	181.21
Engineering, Field	60 00	....	60.00
Painting	27.50	16.53	44.03
Total Transformer House and Equipment	$517.64	$4,109.53	$4,627.17

TABLE 15.—*Assay Office*

	Labor	Material	Total
Excavation	$23.25	....	$23.25
Concrete	13 14	$8 52	21.66
Machinery, f o.b. Oatman	....	152.97	152.97
Machinery, Erection	31 89	1.37	33 26
Building Lumber	....	296.06	296.06
Lumber Framing and Erection	107.90	4 86	112.76
Building Covering in Place	....	89.70	89.70
Doors and Windows in Place	33.00	38.27	71.27
Wood Tanks, f.o.b. Oatman	....	53 35	53.35
Wood Tanks, Erection	0 75	....	0.75
Piping, f.o.b. Oatman	......	7.65	7.65
Electric Wiring, f.o.b. Oatman	....	27.72	27.72
Electric Wiring, Erection	27 56	....	27.56
Belting in Place	....	2.25	2.25
Engineering, Field	6.65	....	6.65
Furniture and Fixtures	68 13	623.32	691.45
Painting	18.13	10.41	28.54
Small Tools and Equipment	127.50	395.32	522.82
Total Assay Office	$457.90	$1,711.77	$2,169.67

TABLE 16.—*Inclined Tramway*

	Labor	Materia	Total
Excavation	$127.75	$0.57	$128.32
Concrete	12.06	8.52	20.58
Machinery, f o.b. Oatman	....	806.37	806.37
Machinery, Erection	37.77	63.69	101.46
Lumber Framing and Erection	13.37	....	13.37
Electric Wiring, f.o.b. Oatman	....	1.41	1.41
Electric Wiring, Erection	26.62	....	26.62
Engineering, Field	6.45	....	6.45
Painting	....	0.28	0.28
Total Inclined Tramway	$224.02	$880.84	$1,104.86

TABLE 17.—*Water System*

	Labor	Material	Miscellaneous	Total
Bergman Ranch:				
Well and Pit	$1,425 07	$680 57	$49.41	$2,155.05
Plant and Building	....	272 87	....	272.87
Pumping Machinery, f.o b. Site	....	1,480.04	....	1,480.04
Pumping Machinery, Installing	21 62	10 92	1 00	33.54
Electrical Equipment, Installed	35.62	1,439.98	5.90	1,481 50
Pipe and Fittings, f.o.b. Kingman	....	8,727.80	....	8,727.80
Pipe and Fittings, Hauling and Distribution	....	1,406.85	....	1,406.85
Two Storage Tanks, Installed, 75,000 Gal.	32.25	1,546.87	....	1,579.12
One Small Tank	....	71.10	....	71.10
Pumpman's Residence	91 27	886.47	....	977.74
G. A. Heckler, Contract	15 00	56.00	3,179.00	3,250.00
Engineering, Field	71.45	....	86.00	157.45
Total Bergman Ranch	$1,692.28	$16,579.47	$3,321.31	$21,593.06
Well Test	$126 75	$30.96	....	$157.71
Big Jim to Mill, System:				
Engineering, Superintendence, Maintenance	$6.00	....	....	$6.00
Pipe and Fittings, f o b. Oatman	....	$2,169.34	....	2,169.34
Pipe and Fittings, Distribution	43.11	....	....	43.11
Installing Line	238.70	0.46	....	239.16
Storage Tank, Installed Complete	90.50	....	....	90.50
Total Big Jim to Mill, System	$378 31	$2,169.80	....	$2,548.11
Total Water System	$2,197.34	$18,780.23	$3,321.31	$24,298.88

DISCUSSION

JOHN B. HASTINGS, Los Angeles, Cal. (written discussion).—This paper reminds me that when I had an option on a Nevada mine, where the only orebodies assayed $4 gold, I went to San Francisco to learn the cost of putting broken ore in a 25-ft. vein on the mine cars, and sought Mr. Alfred Wartenweiler, who said "There is not a mine in California that can tell what it costs to move ore in the stopes."

When building small mills in the mountains, and with only 30 or 40 employees, by entering in a log at night the work performed by each man, I have been able to plot the costs with the accuracy shown in this paper, and very good discipline it is. Cost of new construction and repairs is carefully kept by most companies, and is compiled after completion; probably the outlay of labor and material in pieces of work sufficiently important to call for blueprints is estimated beforehand, but numberless odd jobs of construction and repairs are so itemized. Might it not be worth while, at a large plant, to have these smaller daily tasks described in advance in a central repair office, and then let inspectors look over the job, report time and material needed, and enter it in sufficient detail in proper ledgers, the men then being sent to accomplish it, and reporting when finished? The forecasts would soon be made quickly and correctly and would give the head mechanic, carpenter, and electrician easy supervision of their men, and the results could be seen at a glance by the managers.

Otis Passenger Elevator at Inspiration Shaft

BY C. E. ARNOLD, B. S., MIAMI, ARIZ.

(New York Meeting, February, 1918)

A BRIEF description of this installation was included in a recent paper by H. Kenyon Burch.[1] The purpose of the present paper is to amplify Mr. Burch's description, as it is felt by the writer that the subject merits more than passing attention.

In making a comparison between the common method of hoisting men in mine shafts, and elevator practice in high buildings, the former shows to great disadvantage both as regards safety measures and smoothness of operation. It is surprising that in view of the inducements offered, the step of applying the building equipment direct to the mine shaft has not been taken before, as in many respects the conditions of service are similar, and the objects to be attained are identical. Even without doing this, it is certain that safety to life and limb in the usual method of hoisting men underground can be greatly enhanced by the application to the mine hoist of some of the features of the building elevator.

In the case under consideration, the elevator cage runs in a vertical, concrete-lined shaft compartment 5 ft. 11 in. by 5 ft. 6 in. (1.8 by 1.68 m.) in section and 585 ft. (178 m.) deep, while the counterweight runs in the pipe and ladder compartment of a twin shaft 102 ft. (31 m.) distant. The section of the division of this compartment occupied by the counterweight measures 2 ft. 4¼ in. by 3 ft. 10½ in. (0.72 by 1.18 m.), and the counterweight is made in the form of a small cage which suffices to carry two men for the purpose of making inspections or repairs in the pipe and ladder way.

The hoist is designed to carry a load of 7500 lb. (3401.94 kg.), exclusive of the cage, which weighs 7500 lb., at a maximum speed of 800 ft. (243 m.) per minute. It is installed in the main hoist and compressor building about 220 ft. away from the elevator shaft and is driven by a 160-hp. direct-current motor which is served by a 190-hp. motor generator set. A small direct-current generator mounted at the end of the motor generator set furnishes the current for the controller magnets, brake and fields of the hoist motor and generator. The drum, which is 72 in. (1.83 m.) in diameter, is driven through the medium of a single reduction herringbone gear. A Francke flexible coupling connects the

[1] Mine and Mill Plant of the Inspiration Consolidated Copper Co. *Trans.* (1917), **55**, 707.

motor and pinion shafts, and at the periphery of this coupling the hoist brake is applied.

The cage and counterweight cables are 1⅛ in. (28.575 mm.) diameter. The cage guides are steel and of T section, 6 by 5 by 1 in. (15.2 by 12.7

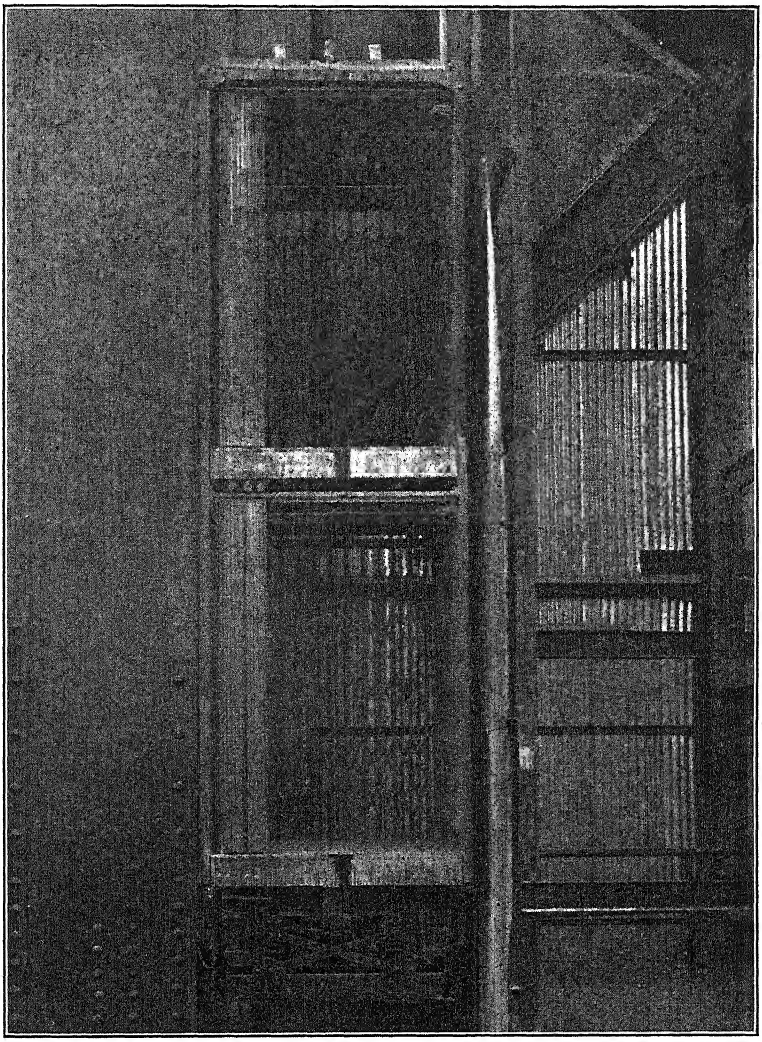


Fig. 1.—Otis elevator at Inspiration shaft.

by 2.5 cm.), with the guiding surfaces planed smooth. These are screwed to steel plates which are anchored to the concrete lining of the shaft by means of expansion bolts. The counterweight guides are of 3½ by 5½-in. pine (8.9 by 14.0 cm.).

The cage is double decked and the sides facing the guides are of solid sheet steel, while the four front and back openings are protected by collapsible steel gates each extending from the floor to the top of the opening. The two halves of the bonnet are hinged parallel to the center line of the guides. The upper deck, on which the operator stands, is provided with a telephone, annunciator, incandescent lamp, emergency switch, and operating switch. The latter switch is self centering, *i.e.*, should the operator remove his hand from the switch when the cage is running, the switch will instantly come to the neutral position. There is a second operating switch in the engine house which can be used after disconnecting the cage-operating switch by means of a throw-over switch which is also located in the engine house. In operating the cage from the engine house, the engineer knows the cage's position by means of an ordinary vertical indicator, and he can communicate with a person on the cage by telephoning, even though the cage be in motion. However, the occasions when there is necessity for operating the cage from the engine house are quite rare.

For signaling the cage operator, there is an "Up" and "Down" pair of push buttons on each landing, and these connect with the annunciator facing the operator. Each landing is likewise provided with a telephone which connects with the cage and engine-house telephones. The elevator operator controls the movement of the counterweight, so that all signaling between the operator and persons riding the counterweight has to be performed by telephone.

The cage ordinarily carries 36 men besides the operator, 16 on the upper deck and 20 on the lower. Sixteen only are carried on the upper deck, in order to leave plenty of elbow room for the operator. The landings are two-decked, so that both decks of the cage may be loaded or unloaded simultaneously.

The installation is equipped with numerous safety devices designed to stop the current supply to the motor and bring the cage to a standstill should the occasion require it. These safety devices are listed and briefly described as follows:

(*a*) *Brake.*—The engine band brake is so arranged that when the current supply to the hoist motor is interrupted the brake is automatically applied. It is actuated by means of a weight, and the pressure of a heavy helical spring, both of which are controlled by an electro-magnet. So long as the current is supplied to the hoist motor, the electro-magnet keeps the brake released.

(*b*) *Gate Switches.*—Each of the four cage gates is provided with a switch connected in series with the controller and it is only when the gates are properly closed that current can be supplied to the hoist motor.

(*c*) *Limit Switch, Emergency Switch and Slack Cable Switches.*—There

is a switch so placed in the headframe that in the case of overwinding the current supply is interrupted.

A hand-operated emergency switch is located on the cage beside the controller.

At the bottom side of the opening through which the hoisting cable passes from the hoist house to the headframe, there is a switch that is opened by means of the weight of the sagging cable, should it become slack. Also, there is a slack-cable switch at the point of attachment of the hoisting cable to the cage.

(*d*) *Buffers.*—There are two long-stroke, oil-cataract buffers located at the bottom of the hoisting compartment, so designed that should the cage pass its lower terminal at normal full speed it will be gradually brought to a stop without shock to the passengers.

(*e*) *Stop-motion Controller.*—By means of a screw-operated controller attached to an extension of the drum shaft, the engine is automatically retarded and stopped at each of the limits of cage travel.

(*f*) *Wedge-clamp Safety Device.*—By means of this device, which is attached to the under side of the lower cage deck, each guide is gripped by a pair of clamps and the cage brought to a standstill upon having attained a speed of 1120 ft. per minute. A governor, which is situated in the headframe, is connected with the cage by means of an endless ½-in. hoisting cable extending the depth of the hoisting compartment. When the cage speed exceeds 850 ft. (259 m.) per minute, the governor, by means of switches, automatically reduces the speed of the hoist motor. When the cage speed reaches 960 ft. (292 m.) per minute, the governor cuts off the current supply to the motor. Should this procedure fail to stop the cage, and the speed reach 1120 ft. (341 m.) per minute, the governor will grip the ½-in. cable and hold it fast. This cable, by means of a short attached cable, then causes the drum of the safety device on the descending cage to revolve, thus causing the clamps to grip the guides. In order to reopen the clamps, the drum is reversed by the use of a socket wrench applied through a small trap door in the lower deck of the cage.

The time required for making the complete cycle of one round trip between the surface landing and the 4th-level station, a distance of 347 ft. (105 m.), is 2 min. 59 sec., being divided as shown:

	Sec.
Lowering	45
Discharging and loading 36 men at 4th level	45
Hoisting	44
Discharging and loading 36 men at surface	45
Total	179

The distances between the surface landing and the six stations served by the elevator are shown below:

Surface landing to

	Feet
Shaft collar	21
3d level	235
4th level	347
6th level	471
Skip loading station	531
Pump station	584

At the time of writing (June, 1917) there are 1000 men employed underground at the Inspiration mine, all of them being carried by the elevator.

Outside of this work, the elevator is running intermittently carrying bosses, engineers, mechanics, etc.; for the transferring of minor supplies such as carbide, oil and tools; and for hoisting mine samples.

The power required for this work amounts to approximately 430 kw.-hr. per day.

Branch Raise System at the Ruth Mine, Nevada Consolidated Copper Co.*

BY WALTER S. LARSH,† E. M., RUTH, NEV.

(New York Meeting, February, 1918)

The Ruth orebody, so far developed, is roughly oval in plan, major and minor axes about 1600 ft. (487 m.) and 1200 ft. (365 m.) respectively, average thickness about 120 ft. (36 m.), and with a general dip of about 15° to the northwest. According to the generally accepted theory, the ore is a secondary enrichment of the porphyry due to leaching *in situ* by meteoric waters. Copper occurs as chalcocite, chalcocite coating pyrite, and a little chalcopyrite. The leached zone, or capping, covering the ore varies in thickness from 110 to 540 ft. (33 to 164 m.), average about 410 ft. (124 m.). The ore is blue gray in color, and the capping, light yellow to brown.

Ore was first discovered in quantity in the workings from the Ruth shaft, now caved. Further development work was done by churn drills, and the outline of the orebody, as stated above, determined in this manner. Drilling is still being carried on.

The porphyry area is entirely surrounded by sedimentaries, limestones, and shales; and, in so far as the underground workings have shown, the porphyry itself, the sedimentaries near the contact, and the country underlying the ore (igneous or sedimentary) is very soft, heavy, and in places swelling ground. All openings have to be carefully and stoutly timbered, and, after once driven, they have to be constantly eased off and repaired.

The mine is at present served by two shafts, the Star Pointer, the main working shaft, a vertical, and the Ingersoll, an incline used for waste and material. The two shafts are about 2600 ft. (792 m.) apart, connected on the 500 level; a connection is now being driven on the 600 level. (Dec., 1917. This connection is now completed.) The 300 level, which is finished, and the 400 level which is nearly completed, are accessible only from the Ingersoll and connections with the 500 level.

The 300 level was developed for and mined by the shrinkage stope system, similar to that used successfully in the Ray Consolidated property.

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* Originally presented at a meeting of the Nevada Section on June 22 and 23, 1917, at Ely, Nev.

† Underground Mine Supt., Nevada Consolidated Copper Co.

This method consists in carrying up stopes 10 to 15 ft. (3 to 4.5 m.) wide on 25-ft. (7.6-m.) centers at right angles to parallel hand-tramming drifts on 25-ft. centers. After the stopes are completed, the pillars between them are caved and the capping allowed to settle. At the outset this method was very satisfactory, but after a considerable area had been caved the weight became so great that the tramming levels could be maintained for the passage of cars only at great expense. Branch raises were then

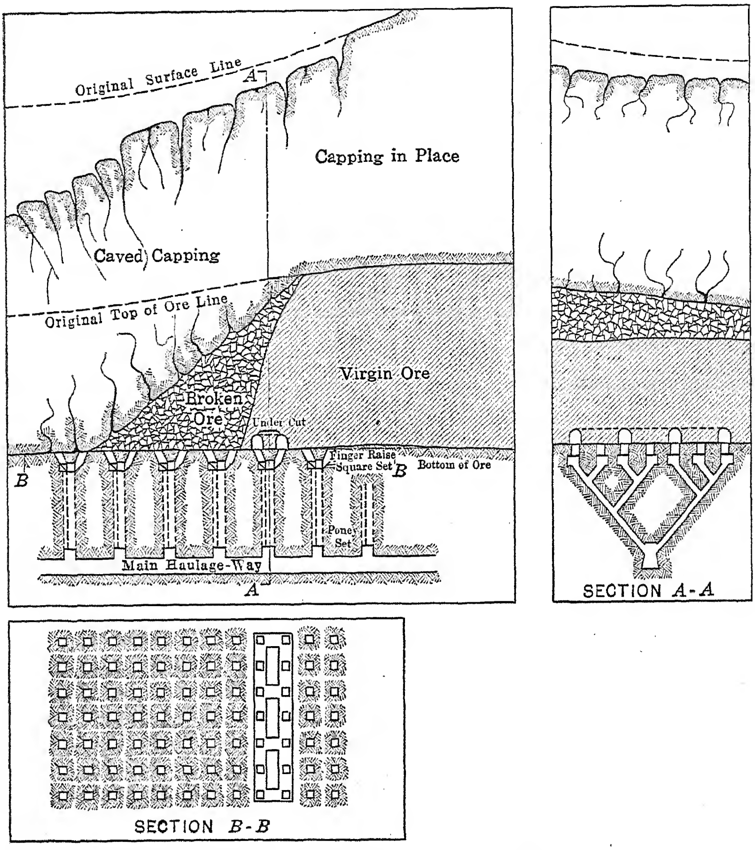


FIG. 1.—BRANCH RAISE CAVING SYSTEM.

run to tap the tramming drifts, so that the ore could be run directly to the motor-haulage level below. It was observed that these branch raises below the working level stood up very well even when the level itself was heavy and hard to hold.

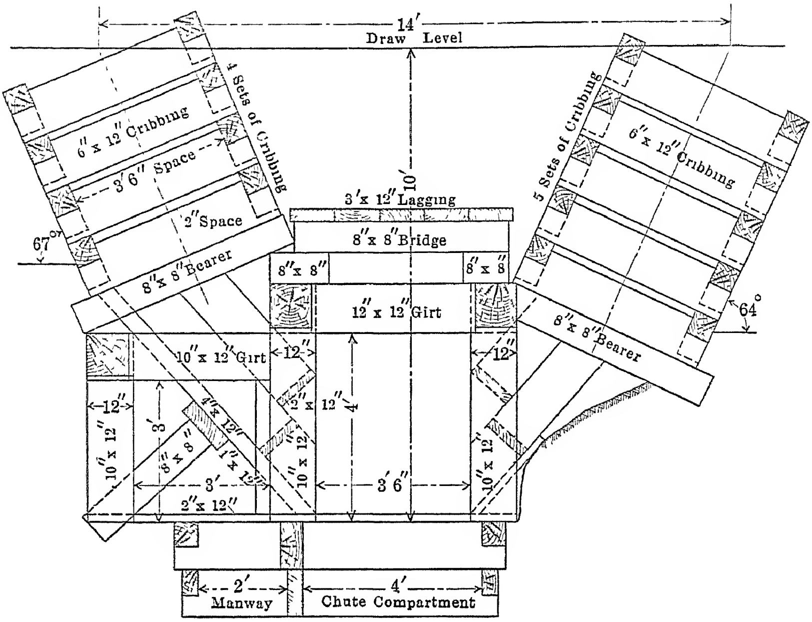
The next step was to do away with the costly tramming level, and after some experimenting with size of raises, position of square sets, fingers, etc., the following system was evolved and is in use at present.

On the 500 level were two parallel haulageways about 200 ft. (60 m.)

apart; a third was driven midway between them. From these haulageways, branch raises are driven (see Fig. 1) so that the branches intersect a plane 50 ft. (15 m.) above the haulageways at 12½-ft. (3.8-m.) intervals. The plane of a raise series is normal to the haulageways, and the series are spaced 25-ft. centers. At the top of each of the branches a square-set is erected, and from this square-set two short finger raises are run (see Fig. 2). Control chutes are placed in the square-set at the bottoms of the finger raises. The tops of the finger raises are spaced 12½-ft. centers in the direction of the plane of the raise and alternately 14- and 11-ft. centers at right angles to this plane, the 14-ft. spacing coming over the square-sets and the 11-ft. between fingers of two raise series. In starting the raises off from the haulage level, a pony-set 5 by 6 by 6½ ft. (1.52 by 1.82 by 1.98 m.) is erected over it and the raises run from this. The raises are all two-compartment (manway and chute) to the square-sets, they are cribbed with 4 by 12 in. (10.16 by 30.48 cm.) or 6 by 12 in. (15.24 by 30.48 cm.), depending on the ground, and are 3 ft. by 6 ft. 4 in. (0.9 by 1.9 m.) inside dimensions (chute 3 by 4 ft., manway 2 by 3 ft., 4-in. divider). The fingers are 3½- by 3½-ft. square, 6- by 12-in. cribbing. Arc gates are used in the pony-sets, plank gates in the square-sets, and a grizzly, made of old rails, in the square-set at the top of each branch.

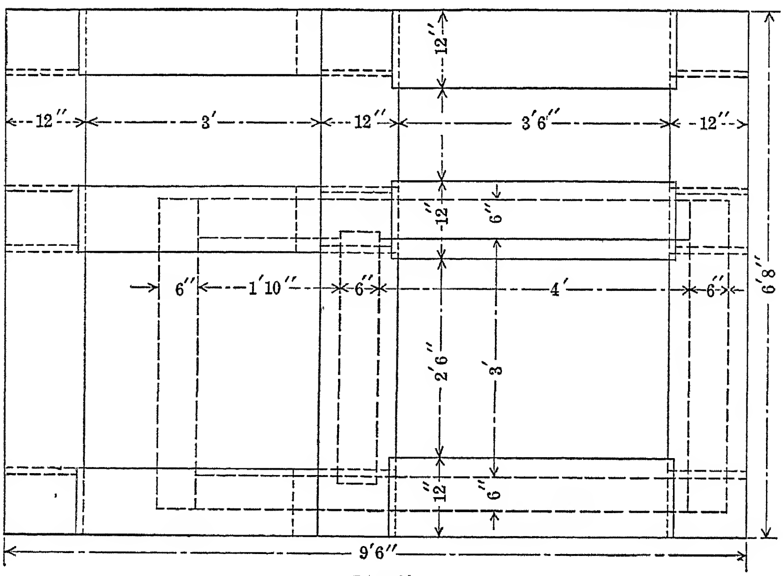
The plane or slightly warped surface connecting the tops of the fingers is considered the "draw" level, though no level is maintained here. In mining, the tops of the fingers in a raise series are connected by drifts, where the ground will permit; at every other branch the drifts are connected by short crosscuts, the small pillars left between drifts and crosscuts drilled and blasted so that a clean undercut or slice is made at the "draw" level. In starting out a new block, it is sometimes necessary to carry up a stope for a short distance over the first raise series, but after one or two have been undercut the ground above the draw level caves readily, and all that is then necessary is to undercut each succeeding raise series, running the crosscuts to the cave already formed and shooting the pillars to the cave. As there is a finger raise every 12½ ft. (3.8 m.), the undercutting can be started almost anywhere. If the ground is too bad to permit undercutting drifts, as much of the work as possible is done from the tops of each finger. It is never very difficult to start a cave in the Ruth. The men always work in virgin ground and in small openings in driving the raises and in undercutting. After the undercutting is done and the draw started, chutes are placed in the two remaining sides of the square-set, not occupied by the finger raises, but no fingers are run here.

The critical part of the whole system is to draw the ore properly after it has been caved. Care must be taken to pull the ore down evenly so as not to mix capping with it. The expectancy of each raise series is calculated, from all available data such as drill holes, raises, or other



SECTION

FIG. 2*a*.



PLAN

FIG. 2*b*.

SQUARE-SET AND FINGER RAISES, RUTH MINE.

workings, and charted. From the charts, a working model showing the position of the capping over each chute is made up. The amount to be drawn from each finger is determined by the stope engineers from the charts and model and is given to the foreman and bosses each shift. The angle of the contact between ore and capping from the raise series completed to those being brought in is maintained between 30° and 40°.

The amount drawn is estimated by the chute tappers and draw bosses in the raises. They report this to the stope engineer. This estimate is balanced against the number of motor cars drawn from the raises, and the discrepancies proportioned back to the fingers. While this method is not absolute, it is not practicable actually to measure the amount drawn from each finger. As the capacity of the motor cars

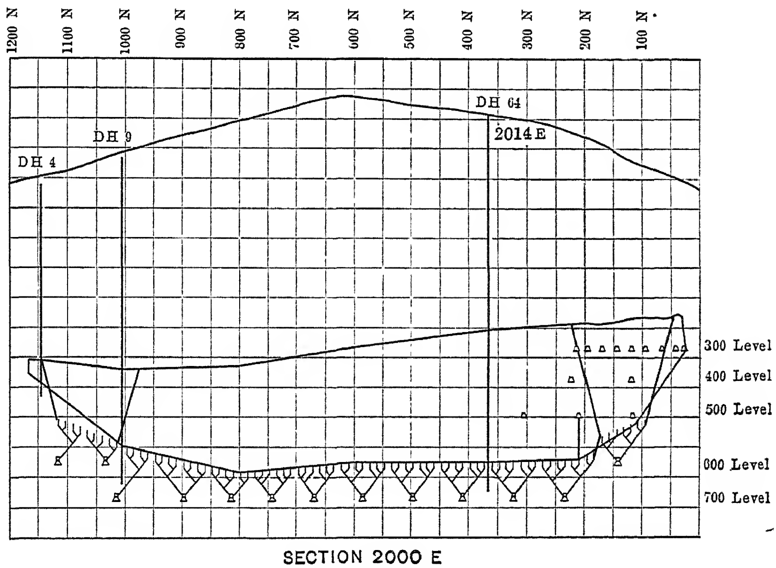


FIG. 3.—SECTION THROUGH OREBODY, SHOWING PROPOSED LEVELS AND RAISES.

is definitely known, a very good check is obtained from them; the errors compensate, and the differences between "estimates" and actual car measurements are not very great, as with practice the chute tappers become very adept in estimating (the cribbing in the raises, which are all standard size, is of very material assistance in estimating the draw).

After the draw is balanced, it is plotted on the charts. The model is then adjusted from the charts, the amount to be drawn from each place noted and the draw sheets made out for the underground men. The charts and model are kept up daily and each shift is given its draw sheet.

The haulageways and raises from them on the 500 level are in ore, so that in drawing this ore from the next lower level the timber will be drawn in and give some trouble. The mine is now being opened up to

bring the "draw" level at the bottom of the ore except where the lift, or height of ore to be drawn, will exceed about 125 ft. (38 m.). The bottom of the orebody, as determined by the churn-drill holes, was contoured and the levels laid out to give a maximum height between draw and haulage level of 80 ft. (24.39 m.) and a minimum of 40 ft. (12.19 m.). As the raises are maintained on a 50° angle, the spacing of the haulage drifts is controlled by the distance between the haulage level and the bottom of the ore. Considering drifts to cost $25 and raises $10 per ft., and allowing sufficient pillar over the drifts to protect them, the most economical distance between draw and haulage level has been demonstrated to be 60 ft. (18.29 m.).

In only one portion of the mine has the draw been completed over an area large enough to use the results as a basis of future expectations. In Block No. 1, 500 level, between raises No. 17⅛ and 19⅝, a distance of 250 ft. (76 m.) area drawn 250 by 225 ft., the following results were obtained:

Expectancy		Extraction		Tons Recovery	Copper Recovery
Tons	Grade, Per Cent.	Tons	Grade, Per Cent.	Per Cent.	Per Cent.
239,437	2.23	251,508	2.07	105	97.8

Better results in extraction are obtained in drawing over a fairly large area than in drawing a high narrow orebody, as the ore has a much better chance to cave. Drawing too rapidly causes chimneys to run through to the capping, and these are always to be avoided.

The proposed development plan for the mine gives an average height of lift of 97.5 ft. (29.7 m.) and average distance between draw and haulage level of 62 ft. (18.8 m.). A portion of the orebody which has a thickness of about 200 ft. (60 m.) will be split by the 600 level into two lifts; the remainder will be mined in one lift.

Incline Top-slicing Method

BY W. G. SCOTT,* METCALF, ARIZ.

(New York Meeting, February, 1918)

INTRODUCTION

SINCE devising the incline top-slicing method in use at the Coronado mine,[1] I have had numerous inquiries as to how the same system could be adapted to larger orebodies.

Based upon our experience here, I have outlined below some suggestions for its application to orebodies of larger size. Modifications and extensions, of course, would have to be made to take care of different dimensions and irregularities.

In order that one may have a better understanding of the scheme, a brief description of the Coronado method will be given first.

CORONADO METHOD

The portion of the Coronado vein that is worked by the slicing system ranges from 20 to 40 ft. (6 to 12 m.) in width. Preparatory work in this orebody consists of driving sub-levels every 55 ft. (16.77 m.) vertically, or in multiples of 11 ft. (3.36 m.) (which is the height of a slice). These levels are usually driven along the hanging wall until the end of the orebody is reached. Crosscuts, at right angles to the strike, 50 ft. (15.24 m.) apart, are then run from wall to wall, or until the lean ore is reached. They are run in the middle of the block, which is 50 ft. in length and the width of the vein. The crosscut on the hanging-wall side is extended in the wall a short distance for a manway and timberway raise. This raise is carried up in the wall to the sub-level above, leaving a pillar about 5 ft. in thickness between it and the vein. Connections are made every 11

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[1] Described by P. B. Scotland in *Engineering & Mining Journal* (Apr. 7, 1917), **103**, 561.

ft. which serve as entrances to the shrinkages as they ascend and to the slices as they descend.

The shrinkage stope, about 4 ft. in width, is then started over the crosscut; this extends from wall to wall and up to the sub-level or stope above, as the case may be. Drawing-off doors are placed in the crosscut near the center of the shrinkage stope. In our case, two have been found sufficient to handle a stope up to 40 ft. in width. These doors are arranged to divert the ore from the stope directly into the haulage-level chute. Every block of ground is provided with one of these chutes directly from the stope to the haulage level, thus avoiding all transferring. These chutes, incidentally, are taken in with the shrinkage in the succeeding lift. When a block is finished down to a sub-level, a drop is made to the next one and repeated with crosscuts and manway, and lengthening out the chute into a shrinkage stope. A study of Fig. 5 illustrates these various stages.

The proportion of preparatory work runs about as follows for a block of ground 40 ft. wide, 50 ft. long, and 55 ft. vertically between subs, which will produce about 9000 tons of ore. One foot of preliminary work is required for every 65 tons of ore recovered, the drifts and crosscuts being in ore while the raise would be in waste.

Stoping Stage

Referring to Fig. 5, "A" shows the shrinkage drawn down ready to begin slicing. The first procedure is to start to lay a grizzly of regular 10-ft. (3.05-m.) stulls across the shrinkage, leaving an opening of about 12 in. (0.3 m.) between them. The ground is cut out to accommodate the full-length stull. As this work proceeds, sets shown at "B" are erected to catch up the mat above, which at this part of the stope happens to be a similar grizzly to the one just described. These sets are composed of regular stulls and set with considerable batter, the posts resting directly on the ground; sometimes set on footboards if the ground is soft. Caps for these posts are placed at right angles to the grizzly stulls of the previous slice. Fillers or braces, consisting of pieces of stulls about 4 ft. (1.3 m.) long are placed between these caps, thus preventing them from coming together. Placing the sets at an angle prevents the posts breaking down the edge of the shrinkage, in fact, strengthens it, as the overhead weight is thrown directly against the edge. This procedure is continued until the opposite side of the stope is reached.

"C" shows the process of the incline slice commencing at the far side first. Panels 10 ft. (3.05 m.) wide are carried up on each side of the shrinkage until the end-line or mat of adjoining stope is reached. As the work advances, 10-ft. stulls are laid down as sills. Flooring of 2 by

12 plank 12 ft. long is spiked to the sills, which forms a slide for the ore, diverting it into the shrinkage stope. The flooring directly over the shrinkage is laid lengthwise with the latter on top of the grizzly stulls. There are numerous advantages in laying the sills. They serve as a foundation for the flooring which is spiked to them. When the succeeding slice below is started, these sills, which answer as caps, are already in place; thus the laborious work of lifting them up is avoided. As the slice advances, the caps being already in place gives an opportunity for catching up an exposed part with a stull before it is entirely undermined, thus avoiding having to expose a large section of mat at one time, as would be the case if it were necessary to blast out enough ground to accommodate a full set at once. The practice is, whenever the end of a cap is exposed enough for a post, to stand it up. This keeps it in place until the other end is exposed enough for a post, and so on until the panel is completed. By this method, we very seldom have a broken mat (a rare thing in top slicing). Special care must be taken to make a good job of the timbering over the shrinkage. If this trough is properly timbered and not allowed to start moving, and if the caps are caught up well in the inclines as soon as they are exposed, little trouble will be experienced throughout the stope.

If the stope is over 30 ft. (9 m.) in width, it is usually shot down and a new section started. Fig. 6 is a longitudinal section through the stope, showing a panel worked out and shot down. It illustrates the condition of the caved mat, and also brings out considerable detail connected with the system.

Fig. 7 shows conditions of the mat of an adjoining stope of a worked-out section.

The floor is carried up at an angle of about 33° from the horizontal. This angle allows most of the broken ore to roll down directly into the shrinkage. Occasionally some of it needs a little coaxing, which is done with a shovel bent over in the shape of a hoe. The stulls for supporting the overburden are stood up at about an angle of 17° from the vertical. This has proven the best angle to prevent them from riding, with a minimum chance of being shot out. The top ends are curved or hollowed out a few inches to conform to the circumference of the cap. The bottom is set on the ground, and not on the sills.

Table 1 shows a comparison for the last 12 months, taken over the slicing portion of the orebody.

TABLE 1.—*Comparison of Flat and Incline Slicing Showing Stope Averages, Giving Costs per Ton Delivered to Haulage Chutes*

1 Month	2 Tonnage	3 Tons per Man	4 Labor Cost	5 Material Cost	6 Total Cost	7 Average Adjusted Labor Cost	8 Total Adjusted Cost	Remarks
1916								
June	12,295	4.90	0 790	0.272	1.060	0.872	1.144	Flat slicing
July	13,355	4 38	0.835	0.325	1 160	0.975	1.300	Flat slicing
Aug.	13,934	4.20	0.808	0.299	1.107	1 017	1.316	First incline slices tried out
Sept.	11,901	3.98	0.943	0.381	1.324	1.073	1.454	Going through change of system from flat to incline
Oct.	13,270	5.04	0.785	0.341	1.126	0.848	1.189	Going through change of system from flat to incline
Nov.	9,580	6.58	0.689	0.347	1.036	0.649	0.996	Going through change of system from flat to incline
Dec.	12,038	7.16	0.659	0.298	0.957	0.596	0.894	Going through change of system from flat to incline
1917								
Jan.	13,629	8.10	0.672	0.294	0.966	0.527	0.821	Going through change of system from flat to incline
Feb.	10,367	7.60	0.569	0.309	0.878	0.562	0.871	Change of system completed on all stopes
Mar.	13,072	9.30	0.647	0.235	0.882	0.459	0.694	Incline slicing entirely
Apr.	13,141	11.20	0.502	0.280	0.782	0.381	0.661	Incline slicing entirely
May	15,937	11.20	0.445	0.305	0.750	0.381	0.686	Incline slicing entirely

Column 4, labor cost, shows actual cost as it occurs monthly. Owing to the sliding scale of wages, its fluctuations do not do justice to the comparison.

Column 7, average adjusted labor cost, shows comparison of labor cost if the same rate were used over the entire period. In this case the average figures out to be $4.27 per day. Therefore this column shows the difference in cost on that basis.

Column 8, total adjusted cost, shows total of columns 5 and 7, giving average adjusted labor cost plus material cost.

REMARKS

A block of ground 40 ft. (12 m.) wide and 50 ft. (15 m.) long, as just described, worked out from sub to sub, produced at the rate of 2650 tons per month until completed, working two shifts per day, three men on a shift. Conditions were better than the average, partly on account of the width, and partly because the men who were detailed to this block had by this time become more accustomed to the system, but an average of 2000 tons is being maintained over all the blocks through the mine where two shifts are worked.

The stope crew draw off the ore from the shrinkage as required, hoist their own timber, and, in fact, do everything connected directly with the stope.

It is only natural that as the workmen become more familiar with the operation of the system it will tend to increase still further the efficiency obtained.

Chief Advantages Over Flat Slicing

1. Dispenses with shovelers, cars or wheelbarrows; unnecessary in the stopes.
2. Cheaper production; tons per man can easily be doubled.
3. Larger production from a given section of ground. When 50-ft. (15-m.) limit is reached the stope is shot down, allowing another to be started immediately underneath without delay.
4. Less preparatory work and expense for upkeep, especially with the shrinkage method.
5. With ordinary flat-slicing methods, the men may never work again under the mat they lay, where with the incline method as shown, as soon as a section is completed the same crew is started on the succeeding slice underneath, thus they are always working under their own mat. This has proven to be a matter of great importance, a poor and broken mat being practically a thing of the past.
6. As the stope crews are confined to a block, they always use the same chutes or shrinkages until the block is completed. The tonnage, therefore, is easily kept track of, and the efficiency factor of each crew of men can be readily obtained with accuracy.

During almost a year's use, no disadvantages have yet developed with this system.

INCLINE TOP-SLICING METHOD AS APPLICABLE TO LARGER ORE-BODIES

Preparatory Work

In laying out the orebody for stoping operations, it is cut up by sub-levels into 50-ft. (15-m.) blocks (see Fig. 1 and 2, showing methods 1 and 2). A drift is run through the center block lengthwise of the orebody. From this drift crosscuts are run at right angles every 50 ft. to the end of the block. They are run every 55 ft. (16.77 m.) vertically or in multiples of 11 ft. (3.36 m.) (which is the height of a slice). They should be run directly above one another, and are practically duplicates in so far as the size of the orebody on the different levels will permit. They are run off center in relation to the block lines in order to allow the shrinkages and chutes to be carried up in the middle of the blocks. This allows for better drawing-off conditions from the chutes, provided it is necessary to transfer the ore on the sub-levels as at Fig. 5.

The preparatory work necessary in method 1, using small shrinkage stopes for chutes (see Fig. 1 and 3, plan and cross-section of method 1), would be 200 ft. (60 m.) of drifting, and 150 ft. of raising for manways

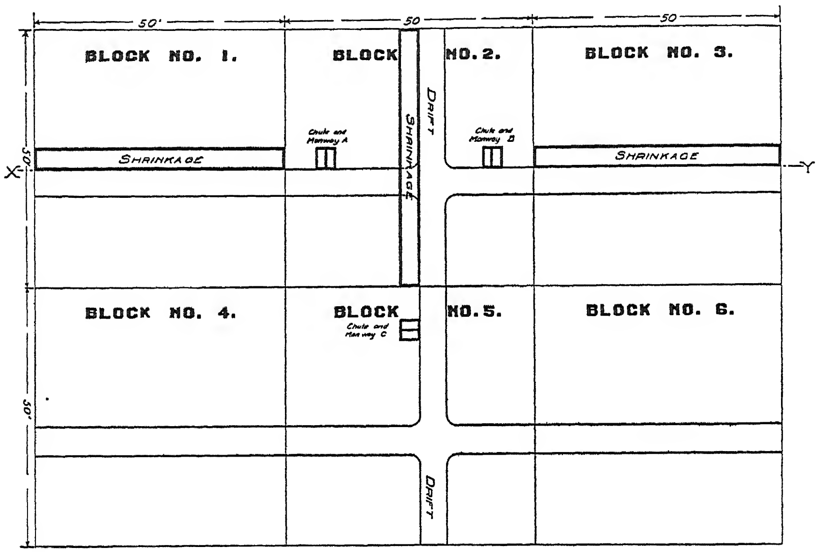

FIG. 1.—PLAN OF METHOD 1, WITH SMALL SHRINKAGES INSTEAD OF CHUTES.

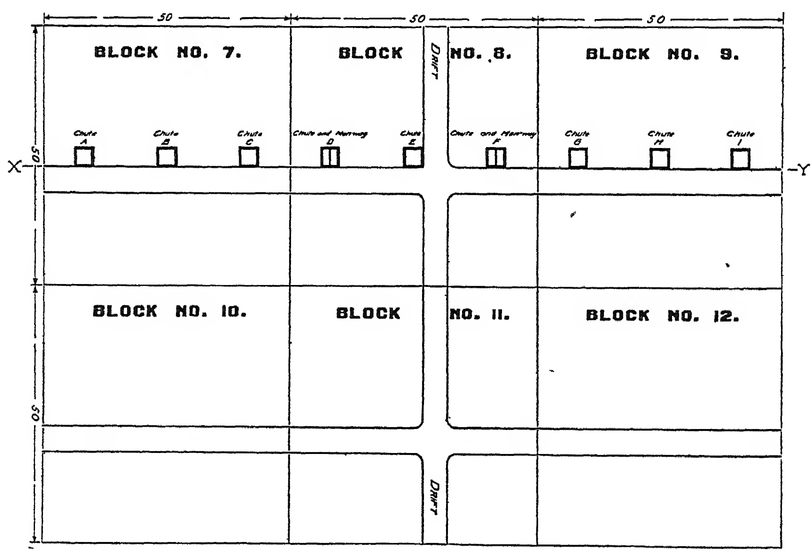

FIG. 2.—PLAN OF METHOD 2, USING ALL CHUTES.

and timberways, amounting in all to 350 ft. This section would contain practically 35,000 tons of ore (based on factors in this district), which would show a production of practically 100 tons of ore for every foot of

preparatory work. The shrinkages are not counted in this. They are run 3 or 4 ft. in width through the block and from sub to sub (see Fig. 3). They produce a good tonnage from the start. All this work would be in ore. No arrangement is shown for disposing of the ore. It is recommended that drawing-off chutes be placed at each sub where the surplus

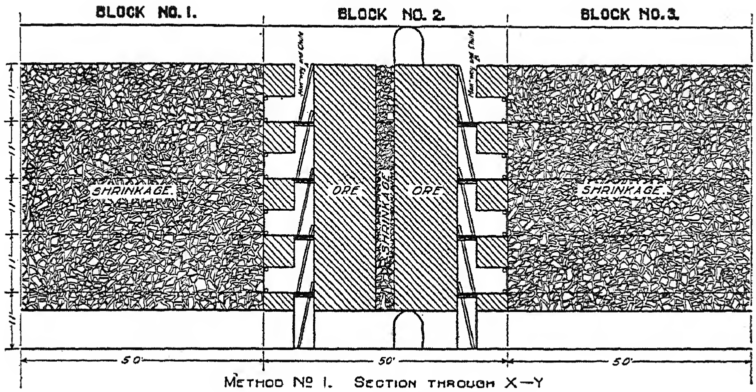

FIG. 3.—SECTION OF METHOD 1.

can be drawn off as required, either into cars and run to transfer chutes, or the chutes from below be arranged to come up into each block and the ore diverted into them direct from the drawing-off chutes (the latter is the Coronado practice). These chutes, later, would answer for part of the shrinkage as the blocks worked downward (see Fig. 5).

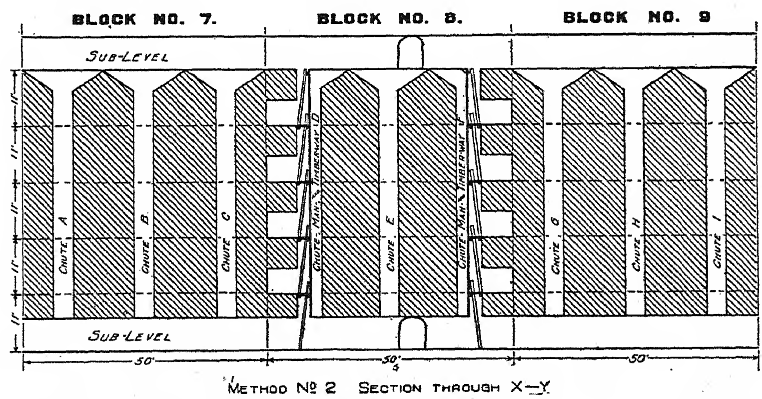

FIG. 4.—SECTION OF METHOD 2.

In method 2, using all chutes (Fig. 2 and 4), plan and cross-section respectively, the preparatory work would be considerably more, amounting to 200 ft. (60 m.) of drifting and 450 ft. of raising, in all 650 ft., which would produce approximately 55 tons of ore for every foot of preparatory

work. This would likewise be all in ore. The drawing off of the ore at the sub-level would be the same as in method 1.

Break-throughs or connections, every 11 ft. vertically, as shown in cross-sections 3 and 4, are run from the manways into the slices and are not figured in, they being taken care of with the stopes as required.

Stoping Operations

With either method, the operation of the slices would be the same. Panels 10 ft. (3 m.) wide are started up on a 33° incline at right angles to the shrinkages or line of chutes. They are always started at the side

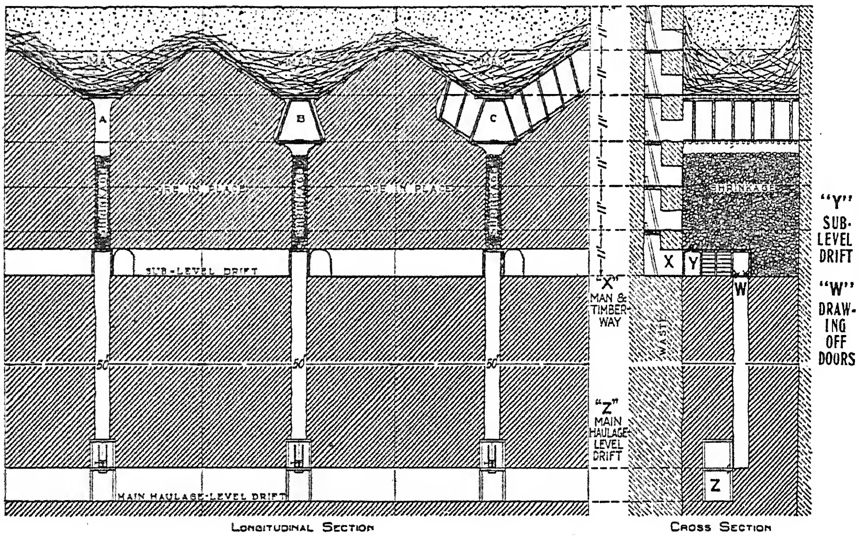

Fig. 5.—Longitudinal and cross-section showing procedure at various stages in either method.

farthest from the manway and run up until the end of the block or mat of adjoining one is reached, and repeated, retreating towards the manway the panels are shot down as fast as they are worked out (see Fig. 6).

Referring to method 1, or the shrinkage method, it will be noticed that it provides manways in the clear of the ore being immediately stoped, so no extra precaution need be observed for a safe retreat, while with method 2, or all-chute method, the reverse is the case.

Details Connected with Method 1

Stope out blocks 1 and 3 first. Entrance to stopes is made through manways "A" and "B," block 2, when blocks 1 and 3 are stoped out down to the first sub-level. Stoping can then be started on block

2, entrance being made through manway "C" in block 5. Entrance to blocks can be made through either top or bottom sub, as is most convenient.

After blocks 1 and 3 are stoped out a couple of floors, and it is decided that block 2 should start producing, entrance can be made to blocks 1

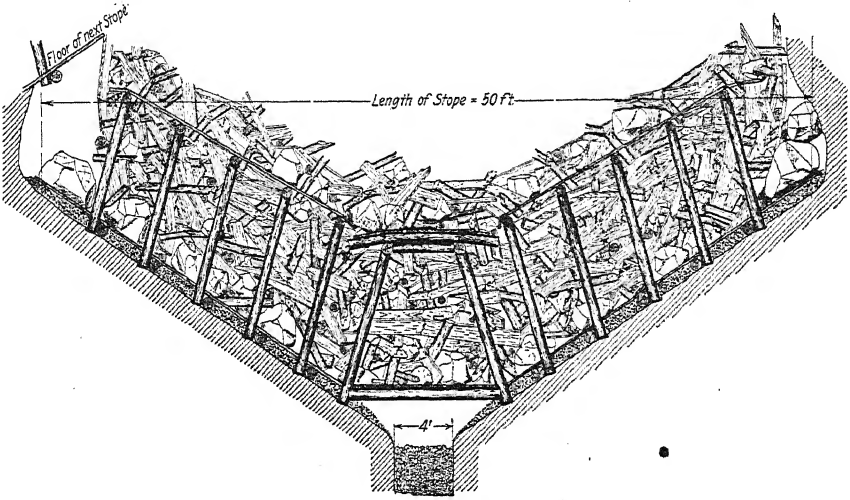

FIG. 6.—LONGITUDINAL SECTION THROUGH A BLOCK SHOWING CONDITION OF A STOPED-OUT PANEL AFTER BEING SHOT DOWN.

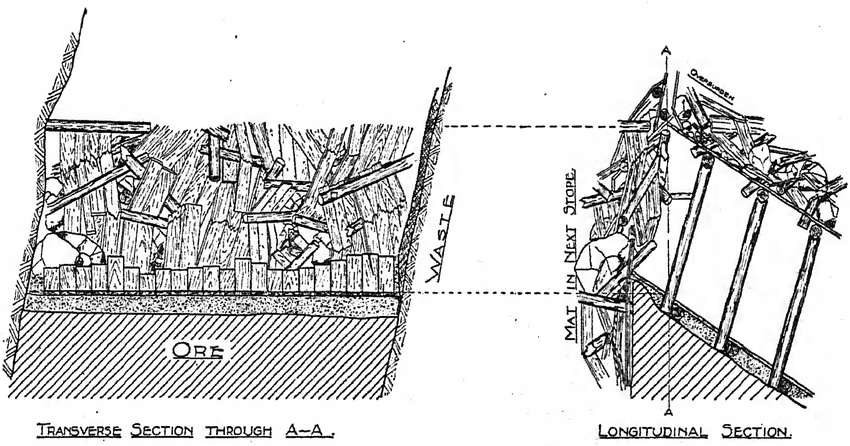

FIG. 7.—SECTION AT THE END OF A STOPE SHOWING CONDITION OF THE END OF AN ADJOINING BLOCK.

and 3 from sub-level below, while entrance to block 2 can be made from sub-level above. Manways "A" and "B" can be bulkheaded over and filled with ore, so there need be no interruption in working the three blocks together in this manner. However, if the latter idea can be

avoided, it would simplify the working conditions if the side blocks could be kept 55 ft. in advance of the middle ones, this being the distance between sub-levels. When the mine is once gotten into that shape, the entire area can then be stoped without interruption. By keeping the middle blocks one sub-level higher all the time, the ventilation of the side blocks would be greatly improved. From a safety point of view, the nature of the ground might not permit cutting these middle blocks or pillars through the center with a shrinkage stope as shown. If there is any doubt about the advisability of this, the shrinkage stope could be left out and a chute run up in the center instead. Thus the block could be mined out as in method 2.

Repeat in the same way with the adjoining blocks, 4, 5, 6, etc. The manway "C" in block 5 will be included in the shrinkage when the latter is brought up in that block.

Break-throughs are run every 11 ft. (3.36 m.) from the manways. They serve as entrances to the shrinkages as they ascend and to the slices as they descend (see cross-section, Fig. 3 and 4).

The manways are all divided off with a timberway on one side.

Details Connected with Method 2

If the ground is too soft to permit the use of shrinkage stopes, chutes can be used throughout instead.

Referring to blocks 7, 8, and 9, stope blocks 7 and 9 down to the sub-level first, entrances being made through manways "D," "F," in block 8. This will necessitate cutting through from "F" to "I" and from "D" to "A" on each floor before starting the slice. This cut, taken out 11 ft. high to the mat overhead, would be producing from the start and should not make much of a break in the tonnage. The tops of the chutes could be inclined toward each other until they almost meet (see cross-section, Fig. 4), which ought to make the production of the stope practically as high as if it had the shrinkage through the center, as in method 1. By having entrances through "D" and "F," block 8, only, it would be necessary to finish 7 and 9 down to the sub-level before starting to stope block 8. This would reduce the number of manways, only two being necessary for the three blocks. If it is not considered advisable to hold the middle block up while the two outside blocks are being stoped out to the sub-level, a manway in each of the blocks 7 and 9 could be added, such as "C" and "G," in which case one of the manways in block 8 could be omitted. This would provide an independent manway for each block, but it is a question whether it will be as convenient as it looks; for, in this method we have to figure on a final retreat at the wind up of each slice. This would be simplified by centering on one of the manways in block 8, such as "D," in which case we will consider blocks

7 and 9 finished down to the sub-level, entrance to same being already explained.

To proceed with block 8, a cut is taken across the stope in the regular way, and up to the mat overhead, connecting chutes "D," "E," "F." Slicing is then started at "F," retreating back, panel after panel, until "D" is reached. All the stoped portion is blasted down, leaving a panel intact around "D." Some extra reinforcing may be necessary to make sure of holding this manway open. This remaining panel is then worked out quickly and shot down. If independent manways were used in each block, the extra precaution for a final retreat would have to be made with each one, where with the method just described the final retreat can be centered on one.

The same procedure is repeated in adjoining blocks, 10, 11, 12, etc.

Remarks

If the ground is quite firm, method 1, with the shrinkage stopes, would be recommended. For example, ground that would hold raises without having to be timbered would be perfectly safe. If there is any doubt about the shrinkages not holding, chutes had better be resorted to, as described in method 2.

The monthly tonnage that could be expected from each of these 50-ft. blocks, working two shifts, would be between 2500 and 3000 tons. If the ore is soft, that could probably be exceeded.

The scheme as described is intended for an orebody about 150 ft. in width, a few feet more or less would make no difference with the proposed design. A much greater width would probably require another set of drifts and crosscuts. Branches or swells that would interfere could be handled separately, something on the order of the Coronado system (see Fig. 5).

DISCUSSION

C. A. Mitke,* Bisbee, Ariz. (written discussion†).—The advantages of the incline-slicing system have been ably pointed out by Mr. Scott, and also by Mr. P. B. Scotland in the *Engineering & Mining Journal*, Apr. 7, 1917. From the standpoint of efficiency and economy this method is far superior to the top-slice system as generally practised. However, as regards ventilation, and the danger of mine fires, it is just as necessary to use a mechanical ventilating system in mines worked by this method as it is in those worked by the horizontal top-slice system. Mechanical ventilation not only improves working conditions in top-slice

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† Received Feb. 1, 1918.

stopes but, if properly designed for the particular mine in question, permits an immediate attack to be made in the event of a mine fire with a greater degree of safety to the men.

In the course of time, incline top-slicing will probably take the place of the horizontal top-slicing system just as the incline cut-and-fill has superseded the horizontal cut-and-fill stoping method. While incline top-slicing has been tried in several districts on a very limited scale with inconclusive results, the Coronado is the only large mine at which it has yet been thoroughly tested, and there it proved to be a complete success. As Mr. Scott's figures show, the tonnage has been more than doubled, with a simultaneous reduction in costs.

As has been the history with all other innovations in mining, considerable hesitation will probably be shown in introducing this method in other mines. For example, when the incline cut-and-fill system was put forward as a substitute for the horizontal cut-and-fill stoping method, many mining men of good repute were doubtful of its success and postponed its introduction as long as possible, giving as their reason certain geologic conditions which would make the incline cut-and-fill impracticable. At the present time, most of the mining companies in the Southwest, who in the past had used the horizontal cut-and-fill system, have already changed over, or are in the process of changing, and have proved that in the majority of cases horizontal cut-and-fill stopes can be successfully operated under the incline cut-and-fill system. Large horizontal cut-and-fill stopes can now be found in only a few exceptional cases, and it is reasonable to believe that economic pressure and a desire for greater safety will ultimately influence the operators in changing their present methods to the incline cut-and-fill system.

One of the objections to the old horizontal cut-and-fill system is that in large open stopes the back is often 25 ft. above the men. This presents a very dangerous condition, as the roof is too far removed to be tested daily. This method is also very inefficient as all the ore in the stope must be shoveled and handled in wheelbarrows or trammed in cars to the chutes, whence it is drawn out of the stope, while all the waste rock must be handled in the same way in order to refill the stope. Even though expensive machinery is suggested for replacing muckers for handling all the ore and waste, nevertheless, it would appear to be working against fate to devise a complicated machine as a substitute for the simpler way of handling the ore and waste by gravity with the incline cut-and-fill system.

The two cut-and-fill systems mentioned above are applicable only to ground that will stand without timber, while the horizontal and incline top-slicing methods are used in softer ground requiring a large amount of timber. The incline system worked out by Mr. Scott and his organization demonstrates that the mucker can be eliminated entirely and the ore

handled by gravity, without the aid of expensive mucking machinery, or the skilled men which such machinery necessitates.

The problem of changing a stope which has been carried up by horizontal top-slicing to the incline method is somewhat more complicated than that of changing from the horizontal to the incline cut-and-fill system. For example, a block of ground which has been developed for horizontal top-slicing usually contains soft ore and will not always permit a small shrinkage stope to be carried up. In such cases, raises have been suggested, and, of course, this ground would also have to be re-developed for incline top-slicing. At the Coronado mine, however, the ground is hard enough to allow the use of a small shrinkage stope which takes the place of wide chutes or storage pockets.

In introducing the incline top-slicing system in other mines it will be advisable to test it for stoping small orebodies until the organization and crew become familiar with it, after which it may be applied to the larger orebodies. I believe a gradual introduction of this system will ultimately result in its wider application to the mining of practically all large orebodies formerly worked by the horizontal system.

Two of the objections that have been made regarding the incline top-slice are: (1) as the ore cannot be sorted, it is necessary to turn both ore and waste into the same chutes; (2) as the back is on an incline the posts are not vertical and the stope is not so safe a working place as one mined by the horizontal system.

As regards the sorting of the ore, experience has proved that the ore is being mined cleaner with the incline system than with the horizontal, for the reason that the mat has not been seriously broken and therefore no large amount of waste from the capping comes into the stope, as it does with the horizontal system. It is also evident that a separate raise at the end of the shrinkage stope, or in the adjacent country rock, could be driven in case it were found necessary to sort a small amount of waste rock from the ore. The shrinkage stope would necessarily have to be floored over temporarily while the waste rock was being sorted out and trammed to the waste raise. After the ore had been carefully sorted, the floor could be taken up and the ore allowed to drop into the shrinkage stope.

An inclined stope has also proved as safe as those formerly worked by the horizontal method at the Coronado. Since Mr. Scott's paper was written, a strike was declared which lasted several months. This was followed by a mine fire in some of these incline stopes and the mine was closed down for a period of nearly six months. During this entire time not a single stope caved (excepting the fire stope, which burned out) and very few timbers were broken. This compares very favorably with horizontal stopes, which often cave when allowed to stand open for only a short length of time.

Measures for Controlling Fires at the Copper Queen Mine

BY GERALD SHERMAN,* C. E., BISBEE, ARIZ.

(New York Meeting, February, 1918)

MINE fires are always dangerous and are frequently accompanied by loss of life during the period of confusion which is apt to follow their discovery. In metal mines, fires may result from the accidental ignition of combustible material, or they may be of spontaneous origin resulting from the rapid decomposition of sulphide. They occur frequently enough to demonstrate the need of some special equipment and a general plan for controlling them, in addition to measures for their prevention. Nearly all the large copper mines have had fires, and the methods of fighting them have been well described in recent papers, notably by C. L. Berrien,[1] R. E. Tally,[2] and others in discussion.

The Copper Queen mine has many shafts, which are connected by underground workings. The deeper parts are ventilated by fans, but in the shallower portions natural ventilation through numerous connecting raises or shafts is sufficient. There have been several fires in the past few years, of which all are extinguished but one, which is under control. These notes cover particularly the preparations that are being made to check a new fire, partially or temporarily, and to facilitate the escape of workmen in the interval before a definite plan of fighting it can be established.

A fire may occur in a shaft or station, or in some working farther away. In case of fire in an upcast shaft, the gas would escape to the surface and the immediate result would probably not be dangerous to workmen, as they could escape by other shafts. In a downcast shaft, however, the gas would be distributed very rapidly throughout a large portion of the mine, and men might easily be trapped and asphyxiated. A fire in mine workings, drift, raise, or stope, would be dangerous in a degree, but the draft there is likely to be less strong than in a shaft and probably a smaller area would be invaded by the fire gases.

At the Copper Queen mine, in all drifts connecting with individual

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[1] Fire-fighting Methods at the Mountain View Mine, Butte, Mont. *Trans.* (1915), **52**, 534.

[2] Mine-fire Methods Employed by the United Verde Copper Co. *Trans.* (1916), **55**, 186.

shafts, systems of doors are now being constructed which may be closed at any moment, cutting off the circulation of air as completely as possible, so as to check or stop the draft. Thus, in case of fire in any shaft, the doors in all drifts communicating with the shaft can be shut immediately and simultaneously, and water can then be turned on through a sprinkling system to put out the fire, if possible. In case of fire in interior workings, the doors of one or more shafts connecting with the section affected will be closed at once, thus isolating the fire district and protecting exits from the mine as well as checking the progress of the fire. In a way, these doors will serve a purpose similar to the collision bulkheads in a ship. Several shafts are already equipped in this manner and all will be, as soon as possible.

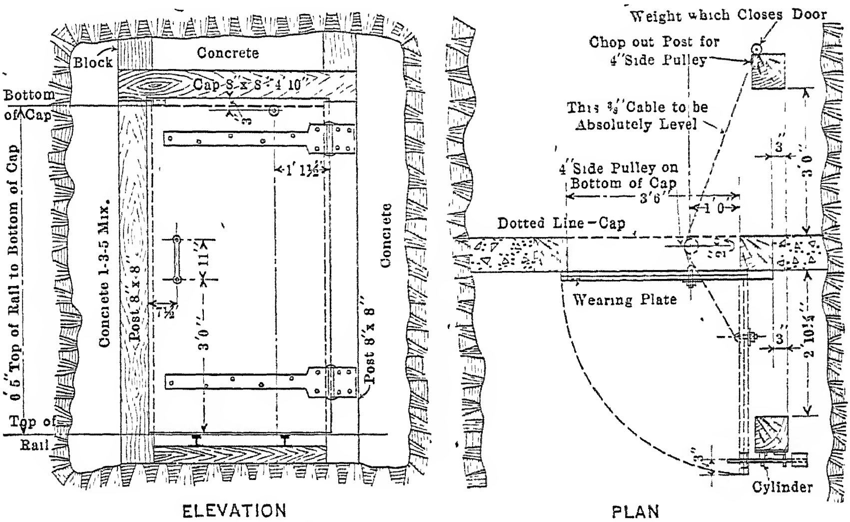

Fig. 1.—Method of mounting fire-door.

A sketch of the doors is given in Fig. 1, and a diagram of the piping system through which they are operated is shown in Fig. 2. Fig. 3 gives details of the operating mechanism. The doors are set in concrete, and are normally held open by a latch; when the latch is thrown, the door is closed by a weight. The latch is held closed by an air cylinder acting against a counterweight. The air cylinders connect by piping with all doors protecting the shaft and with the compressed-air main on the surface. By opening a valve at any station, or at the surface, the air system is drained of air, the pressure on the cylinder falls, the weight throws the latch and allows the doors to close. Any door, of course, may be opened by hand afterward. A small hole in a metal gasket furnishes enough air to supply leakage in the pipe system but not enough to prevent the fall in pressure when any valve is opened. By this arrangement, if anything goes wrong with the piping or air pressure, the doors close auto-

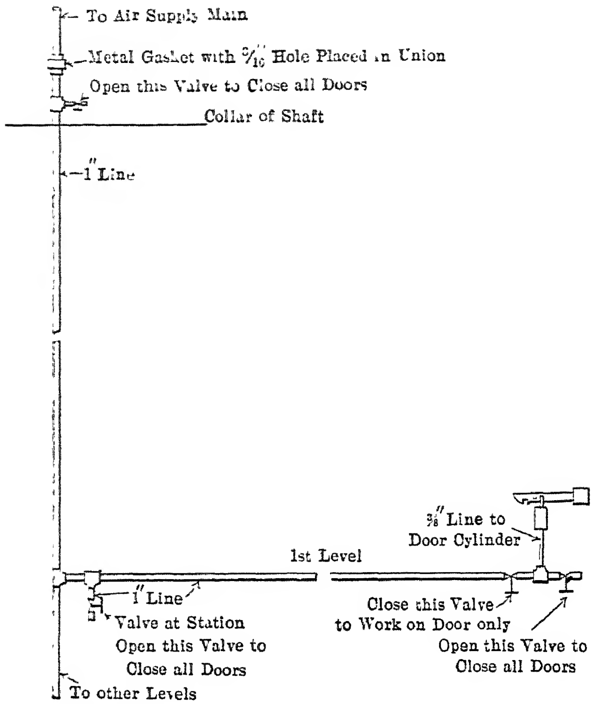

FIG. 2.—PIPE CONNECTIONS FOR OPERATING DOORS.

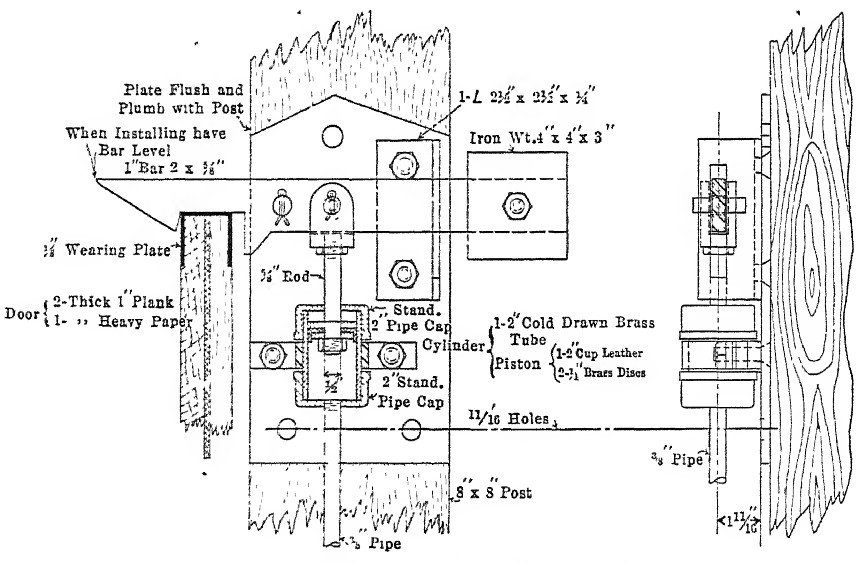

FIG. 3.—DETAIL OF LATCH MECHANISM.

matically; if the latches were thrown by cylinder pressure, instead of the reverse, they would fail in case of accident to the air line or its injury by the heat of a fire not quickly discovered. It is probable that the doors cannot be made air tight, but if necessary they can be easily and quickly caulked by helmet men, after they are closed.

The arrangement would be of benefit whether the shaft be down or upcast. In case of an upcast shaft, the result would be the checking of

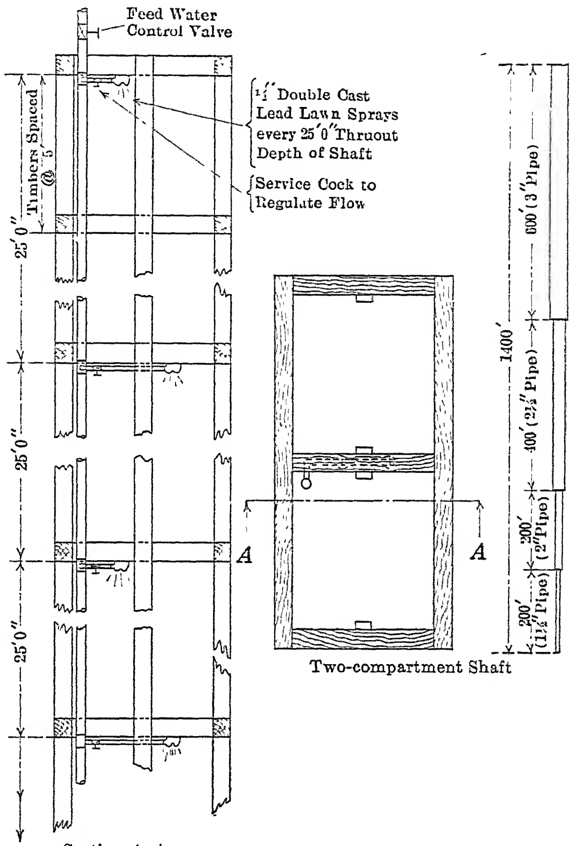

FIG. 4.—CONNECTIONS FOR SPRAYING SHAFT.

the fire to a certain extent because, without the doors, the draft would be increased by the fire. In case of a downcast shaft, it would very largely prevent gas from passing into the mine.

After the doors are known to be closed, it will be safe to turn water into the shaft; but until they are closed, or until all men are known to be out of the threatened part of the mine, it might be extremely dangerous to turn on water, as it would cause a downdraft, whether the shaft is naturally downcast or not, carrying gas and fire into the workings.

Pouring water into the top of a shaft does not seem to be effective in extinguishing a fire, as but a small proportion of it reaches the desired point. Pipe lines are therefore laid down the shafts, which carry water to sprays set under the timbers at 25-ft. intervals and pointing down (Fig. 4). Uniform flow is obtained through all sprays by adjusting a service cock in the line connecting each spray with the shaft main. Water can be turned on only from the surface. By this means, a shaft can be saturated with water quickly and effectively, the only difficulty being that it may be necessary to delay turning on water until the fire has attained considerable headway, and may have damaged the shaft and pipe line sufficiently to interfere with the distribution of water. Fusible plugs could be used in the sprays, but it is feared that spraying at the wrong time might endanger men in the mine. If the stations are timbered, it might be advisable to have sprays with fusible plugs distributed in them.

As at present outlined, the general procedure in case of a fire would be:

1. Giving a general fire alarm, the district in which the fire occurs being indicated by flashing a number on all electric lights on the property.
2. Closing all doors communicating with the dangerous area, and shutting down the fans.
3. Getting workmen to the surface.
4. Turning on shaft sprays.
5. Development of a general plan for fighting the fire or controlling it within certain limits. Those ventilating fans which can be operated safely may be started.

In case of fire within the mine, shaft spraying would be unnecessary unless the fire were so close that it would be desirable to saturate the timbers to prevent their igniting easily.

It is very probable that, in the future, additional doors, which may be closed from the surface as well as from other points, will be placed at various places in the mine; this will divide the mine into sections with the expectation of isolating a fire, checking it somewhat, giving time for men to escape, and permitting a method of fighting to be established, as in shaft fires.

It has been found that serious delays often occur in getting water to a fire, even though compressed-air piping can be connected with water mains and used for the water system. Experiments are now being conducted in the use of a chemical fire engine which may be of assistance in certain cases. However, carbon dioxide from the engine is as dangerous as fire gas, and it would not be safe for men without helmets to use the engine unless the carbon dioxide could be carried away by a positive draft.

A portable fan operated by a storage battery is kept in service, which can supply local ventilation to assist in getting at the fire.

DISCUSSION

Robert E. Tally,* Jerome, Ariz. (written discussion†).—Mr. Sherman's paper embodies two new and very important features: First, automatic closing of doors communicating with the dangerous area; second, the use of a portable storage-battery fan.

His other procedures, such as giving a general fire alarm, getting workmen to the surface, etc., are equally important, but have long been in use in other places. Fire and ventilating doors in connections leading to shafts, air raises, and other large timbered areas, have been in use at other mines; but the method described by Mr. Sherman for operating these doors by compressed air, through a valve on the surface, is, so far as I know, original, and should be installed in every mine where there is danger of fire.

Nearly all large mines are now using artificial ventilation, with the result that there are strong air currents in the shafts and other important workings. The most important feature in mine fires is a quick and positive control of the ventilation, for it takes but a few moments for smoke to travel over a large area, with the usual results of suffocation, and destruction of property.

A strong air current in an upcast shaft acts as a draft in case of fire, and unless quickly cut off the fire would soon get beyond control. An upcast shaft usually changes to a downcast when large amounts of water are used. Human lives are in more danger from downcast currents, as the smoke travels into the workings.

The use of portable storage-battery fans for quick and positive control of smoke in order to get at the fire is an excellent idea, as, in a mine having many doors, the opening of a single door will often reverse the air current. In case of a serious fire it is good practice to station a guard at each door, who will not permit it to be opened unless absolutely necessary. The fan described by Mr. Sherman will tend to eliminate this danger.

Chas. A. Mitke,‡ Bisbee, Ariz. (written discussion||).—Having devoted a considerable portion of my time for the past eight years to problems connected with mine fires, their control and means of prevention, it is with considerable interest that I have read Mr. Sherman's paper on the above subject and Mr. Tally's discussion.

In the fighting of mine fires, and measures used for their control, a number of very interesting developments have occurred during recent years. New devices are available, more rapid means of attack are at

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† Received Feb. 8, 1918.

‡ Asst. Consulting Mining Engineer, Phelps Dodge Corporation.

|| Received May 28, 1918.

our command, and in general the present procedure in fighting a mine fire shows a considerable advance over the old-time custom.

The method employed at the Copper Queen, in stopping circulation by means of fire doors around shaft stations (as described by Mr. Sherman) is excellent in that it permits water to be immediately turned into a burning shaft without endangering the lives of men who may still be in the mine, as the leakage through the doors is so slight that the men have plenty of time to make their escape through another exit before being overtaken by smoke and gas. In mines ventilated by mechanical means (provided the blowers are immediately closed down) these doors would also stop circulation in drifts, raises and stopes, thus preventing the strong artificial currents from feeding a fire in these workings.

This type of automatically controlled fire door, while not a new idea, possesses considerable merit as it can be operated either from surface or underground and the air currents checked almost immediately. This door is really a combination of the old-time iron fire door at shaft stations, which has been in use at the Calumet & Hecla for many years, and the automatically controlled wooden ventilating door of the Copper Queen. In some of the divisions of the mine, these fire doors are of iron, while in others they are constructed of wood. The automatic control of the fire doors by means of compressed air is similar to that used in operating the ventilating doors,[1] the only difference being that the latter has a larger air cylinder, because it requires more power to open the door against the air pressure than it does merely to hold open the fire door by means of a catch. The valve at the cylinder used on the ventilating door is opened and closed by wires and levers so that it can be operated at a distance, while the valve on the fire door is controlled by hand, either on surface or underground according to the pipe connections. The full head of air is left in the small cylinders which hold the fire doors open, and when they are to be closed, valves, either on surface or at the stations, are opened wide to effect a quick release. Then the weight attached to the small cylinder releases the catch and allows the fire door to close. When the fire doors are closed and it becomes necessary to re-open them, the individual doors on each level must be opened by hand.

The air-controlled ventilating doors have been in operation in the Copper Queen mine for four years; at the Calumet & Arizona for two years, and in some of the other mines for an equal period of time.

A storage-battery blower was used at one of the mine fires of the Copper Queen nearly three years ago. At that time it was found very difficult to take it from one level to another on account of the great trouble in transporting the large number of cells belonging to the storage battery. The battery was connected to a 10-in. blower and delivered in the neighborhood of 4500 cu. ft. of air per min. against a 4-in. water

[1] See "Ventilation of the Copper Queen Mine." *Trans.* (1915), **52**, 508.

pressure. A portable 3-ft. Stine fan with long wire connections was also used, which furnished about 20,000 cu. ft. of air per min. against 1-in. water pressure. This fan delivered about four times the volume that the storage-battery blower could possibly deliver and was therefore used a great deal.

At recent mine fires in other camps, a portable Stine fan and one of a similar design were used extensively and proved to be eminently satisfactory. The current was taken directly from the trolley wires, which made it possible to transport and use the fans in all haulage drifts at long distances from the shafts. While this can be accomplished, it was demonstrated in practically every instance that, in order to obtain the utmost efficiency and safety, fans of this size should be located within a reasonable distance of the shafts. Electric connections can then immediately be made, either from the trolley or lighting circuit, and the air coursed so as to take care of the ventilation, smoke, gas, etc., in out of the way places, which eliminates the necessity of using storage-battery blowers of small capacity in these remote workings.

In these recent mine fires, which have been some of the largest in metal mines, very little work was done by men using oxygen helmets, and the operations were remarkably free from the more or less serious accidents and the customary number of men overcome with smoke and gas which formerly accompanied and were looked upon as the natural result of the old-time fire-fighting methods. This has been made possible by a more extensive application of the principles of mechanical ventilation to the work of fire fighting.

Canvas Tubing for Mine Ventilation*

BY L. D. FRINK,† A. B., BUTTE, MONT.

(New York Meeting, February, 1918)

THOSE actively interested in mining are fully aware of the ever-increasing difficulty of making conditions such that efficient work can be done in underground openings, especially as higher rock temperatures are encountered in depth. This is also true where an effort is being made to cut down the burden of overhead expense by working headings 24 hr. in a day if blasting is done as often as is possible in that time.

That the conditions resulting from both these causes have driven the native-born Americans from the mines and that their places have been taken by less efficient foreigners is a fact that we must all admit. The great war now being fought in Europe and the educational qualification clause written into our immigration law by the last Congress will probably limit very materially the supply of labor, such as we are now using in our mines, and will force upon mine operators the necessity of making this work appeal again to Americans.

Metal tubing, with blower or exhaust fans, has long been used in supplying air to dead ends where natural ventilation is impossible, or in driving the smoke from such places, or in doing both, as the need might be. Here in Butte we have now come to use canvas tubing very extensively and find that it has many advantages not possessed by the metal. The use of flexible tubing is not new, but it has not been generally used in mining operations. Recent improvements, however, in the canvas itself and in the jointing of sections and manner of suspension have so increased its usefulness that it promises to add much to the efficiency of mining. There is now on the market a product that is impervious to air, is fireproof, and has a system of jointing which permits it to be put up or taken down in a few seconds.

In this article an effort will be made to explain the manner in which canvas tubing is being used in the North Butte company's operations at Butte, Mont. The accompanying photographs will, I hope, help make clear what may be done with this material.

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* Originally presented at a meeting of the Montana Section, in February, 1917.

† Supt., North Butte Mining Co.

As Used in Shaft Sinking

Early in 1916, the work of deepening the Granite Mountain shaft from the 3100 to the 3700-ft. (945 to 1128-m.) levels was commenced. A good crew was secured and satisfactory progress was made for a few months. Conditions, however, got poorer and poorer as greater depth was attained, the men whom we considered the best workmen and leaders dropped out one by one and their places were filled. In June, but 60 ft. (18 m.) advance was made and it was evident that some means of bettering conditions must be devised. July's advance of but 50 ft. (15 m.) left no doubt that the remaining 150 ft. (45 m.) to be sunk would take a long time if the effort to ventilate that had by then been started did not prove successful.

The Granite Mountain shaft is a downcast; there is a good supply of air on the 3000-ft. (914-m.) level; a fan with galvanized tubing running from the 3000 down the shaft in the pump end of the chippy compartment had been considered. You who have had experience with galvanized tubing are fully aware of its drawbacks. You know how slowly it goes together and also that there are always many leaky joints; you know that galvanized tubing is flattened very easily by concussion and is often ruined even when care is taken not to bring it too close to the blast.

Knowing these drawbacks to the use of metal tubing, the engineers in charge decided to try a canvas tubing that came out about the time that the work on the Granite mine was begun. This tubing, as secured, had no attached means of joining sections. Connections were made by slipping two ends over a wide (6-in.) metal hoop and holding the canvas in place by wiring it there. When two lengths were joined in this way it took but a comparatively slight weight to pull the sections apart, and probably concussion would have worked the same result. Later it was found that a joint such as is shown in Fig. 1 answered every condition imposed upon it. It will not only support the weight of the canvas, but will hold a much greater load, as was shown in many tests, men even swinging their full weight on the lower section. It is reversible, and also has an added advantage of great importance, that is, it can be taken apart or put together while the fan is running. The canvas that covers the ring, being sewed in at each end of each length, acts as a gasket and prevents any air leakage. Each ring has a slip joint, one showing at the bottom and the other at the top of the illustration. The rings are made the same size and either may be put within the other by contracting one ring. When placed together, they form a circular channel. Each length of tubing comes with such a ring sewed in at each end, and when two are put together the canvas forms the gasket to prevent leakage. In drifts and crosscuts, tension bands similar to the suspension ring used in shaft work are put over the joints at required intervals; slack in the

tubing is taken up and it is prevented from drawing back by wiring the tension band to the clamp that grips the messenger wire. The stronger the pull, the tighter the grip. In use, the sections are put together so that the current is from the end that slips in toward the end that slips over. Supporting rings (at right in Fig. 1) were made from galvanized iron. These were put over the joints and, with wires, the tubing was hung in the shaft. At the first installation, 500 ft. (152 m.) was taken down, and one could not help noting the advantage in handling it as compared with the metal tubing, when three men and the total length were put on the cage together. An equal length of galvanized iron would have made about eight deck loads or eight skipfulls. The stringing of the canvas took about 2 hr. and the fan was then put to work.

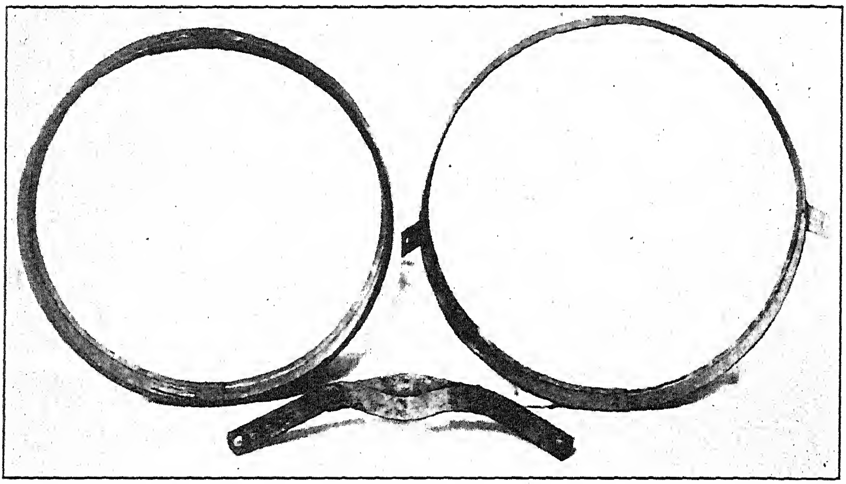

FIG. 1.—RINGS FOR MAKING CONNECTIONS. AT THE LEFT, TWO RINGS PLACED TOGETHER AS WHEN TWO LENGTHS OF TUBING ARE JOINED. AT THE RIGHT, A RING SUCH AS IS USED IN SUSPENDING THE TUBING IN A SHAFT. THE CLAMP AT THE BOTTOM IS USED IN DRIFTS AND CROSSCUTS.

It is not always safe to accept, as their true opinions, what men working in a place say to your face, but after only a shift or two the best shaftmen were back again looking for a place in the shaft, and we knew then that working conditions were much improved and that results could be expected.

The month of August gave 132 ft. (40.24 m.) advance and the 20-ft. (6 m.) sump below the 3700 was cut in a few days in September. By using pieces of varied length, the tubing was kept as close to the bottom as the shaftmen wished it to be. Of course, in adding lengths the lowest piece was always removed and the new piece placed above it. By doing this, what may be called a blasting piece was always kept at the bottom and stood the abuse when a round of holes was spit. No great difficulties

were encountered in the use of the tubing in the shaft. From time to time the supports had to be lowered because of stretching of the cloth, and there were a few holes to be sewed up where the tubing was cut occasionally by flying rocks. Velocities of the air taken at the discharge averaged a little over 5000 ft. (1520 m.) a minute. Rock temperatures in drill holes on the stations at the 3600 and 3700 ranged between 100° and 105° F.

Judging from the volume of air delivered at the bottom of the shaft and from the fact that the men at the bottom would not let the lowest length be kept down close to them, I am sure that the No. 4 Sirocco fan we used blowing through a 16-in. (40.64-cm.) tubing was larger than was necessary. A No. 3 fan with a 12-in. (30.48-cm.) tubing would surely have answered as well.

As Used in Crosscutting or Drifting

Success had been so complete in the ventilation of the shaft that it was decided to put a fan and some tubing in a crosscut being driven to the Rainbow. The problem here was very different. Water temperatures taken near the breast gave 65° F. This is probably pretty close to the rock temperature. While this is all that could be desired as a working temperature, the accumulation of powder gas at the breast made it impossible to keep a full shift, and rounds were repeatedly lost. The problem here was not to cool the place but to clear it of smoke. The breast was 2100 ft. (640 m.) from the nearest supply of air, an upcast raise with a temperature considerably higher than that at the breast of the crosscut. A fan house was put up over this raise and 16-in. (40.64-cm.) tubing run to a booster fan 1500 ft. (457 m.) in. Here it was picked up and sent through tubing to the breast. Though the joints between sections were the same here as in the shaft, the means of support was necessarily different. A messenger or suspension wire (No. 8 galvanized) was stretched with the aid of the common "come along" used by the electricians in putting up trolley, the ends being fastened to stulls put in the crosscut. At convenient places ranging from 25 to 40 ft. (7.6 to 12 m.) apart, sprags were put up and the messenger stapled to them to prevent sag. In the hem of the tubing, at 3- or 4-ft. intervals, two grommets or eyes were inserted, and in these were fastened wire clips or hangers. By means of these hangers the tubing could be rapidly hung to the messenger and made fast there by bending the hangers together with a nail, the carbide lamp stick, or any pointed tool made for the purpose. Between the sections, a tension band similar to the suspension ring used in the shaft was placed over the joints and when the slack was taken up it was wired to a clamp (Fig. 1) that caught the messenger and pre-

vented the tubings from drawing back. The fan when started delivered about 2500 cu. ft. (70 cu. m.) per minute at the end of the line.

The next morning when we went to see what results were being obtained, much to our consternation we found that each low place in the tubing was a reservoir, weighted down with water. We had not thought of the condensation that was bound to come with the cooling of the air as it went into cooler surroundings. The conditions at the breast, however, were much better than they had been, and the shift could easily work there. Cheered by that fact, we went back along the tubing,

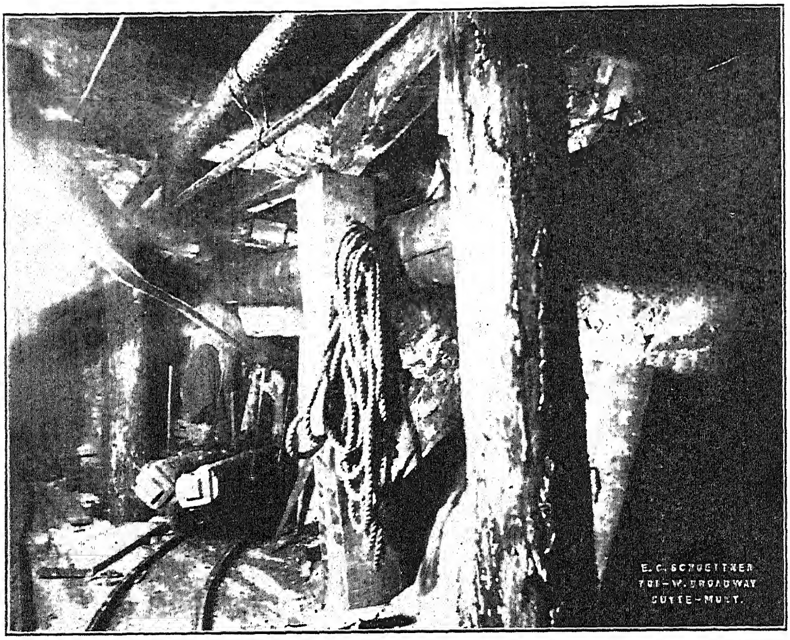

FIG. 2.—CANVAS TUBING IN A PLACE WHERE IT WOULD BE IMPRACTICAL TO PUT GALVANIZED IRON TUBING.

disjoined the sections, and ran the water out. After we had put them together again, we sat down to plan a way to overcome the difficulty. As it was evident that we could not stop the condensation, we decided to put grommets in the bottom at both ends of each section. There being but little pressure, these grommet eyes could easily be kept corked to prevent air leakage. By shutting down the fan for a few minutes each morning, the ditch man could run all the water to the ends, pull the corks, tie up a short section and move on to the next joint to do the same. By the time the last sections were drained, he could start back along the line untying the canvas and replacing the corks. All would then be well for another 24 hr. We later found that the booster fan was not necessary, and the tubing was connected straight through, making, before the crosscut was finished, a 2400-ft. (731-m.) line.

While conditions at the breast of this crosscut could not be made what we should have liked to make them, because of the poor supply of air that of necessity had to be used, the place was put in such shape that a round was seldom lost and the men stayed with the job, with but few changes, until the 300-ft. advance, to hole, was made. When holed, the breast of the crosscut was just a mile from the Granite Mountain shaft, the source of the air supply.

This was the first line that had been run in a crosscut and we were pleased to find how easily the tubing conformed to the bends. Where

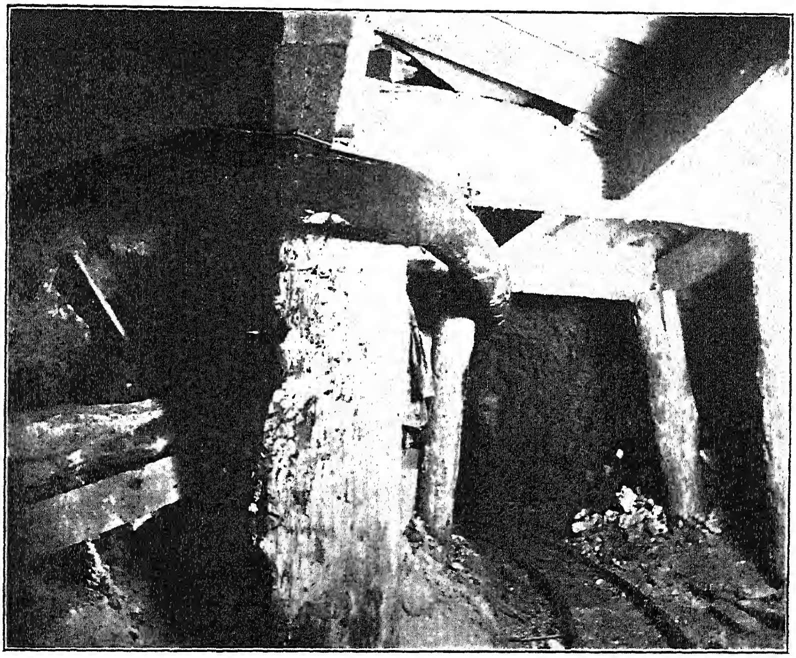

Fig. 3.—Canvas tubing rounding a curve.

galvanized pipe would have been hard to install because of jutting rock or slight turns, the canvas passed around them in smooth curves. Elbows to fit any angle were easily made by cutting the tubing to pattern, as a tinsmith cuts elbows, and sewing the two ends together.

In this crosscut, some difficulty was experienced with the leading length until a successful blasting piece was made. This piece was made up with harness snaps fastened to ears sewed to the hem of the tubing so that it might easily be put up or taken down. Before spitting a round of holes, this piece was detached and carried back to a safe place. This would leave the discharge far enough away from the breast to be safe from flying rocks and the effects of concussion and still close enough

so that the smoke would quickly be driven out. When the next shift came on, they would replace the blasting piece so that the air might blow directly on them.

On the 3000-ft. (914-m.) level in a drift, we are able to supply good air to the breast with a No. 2½ Sirocco fan blowing through about 500 ft. (152 m.) of 10-in. (25.4-cm.) tubing. In this length there was one place where the water ran on the tubing in streams. The canvas showed no ill effects from the bath. The cost per linear foot of driving was reduced about 50 per cent. in this drift and no difficulty was experienced in keeping men. It was here learned that air motion was a great factor in making favorable working conditions. There was but a slight difference in the temperature and humidity of the air as it blew on the men and that of the drift 50 ft. back where the air velocity was slow, still one felt comfortable and could work at the breast while but little could have been accomplished were the work to have been done 50 ft. back. One man, in speaking of this fact, said he could easily understand it, for, when a day was hot and unbearable, if he went out in his auto, as soon as he got up a little speed, he was cool enough. It would be hard to get the men to move as fast as that underground, but the air can be made to move, as is attested by velocity readings of from 4000 to 5000 ft. (1219 to 1524 m.) per minute recorded at the discharge of most lines not over 500 ft. (152 m.) in length.

On the 3200, 3400, and 3600 levels, considerable use has been made of the canvas tubing in blowing to the breasts of the crosscuts. The rock temperatures on these levels are quite high, being 100° F. at the 3200, 102° at the 3400, and 104° at the 3600. As yet a separate fan has not been put on each of these levels. All the air is supplied by a No. 6 Sirocco fan blowing from the 3000-ft. level. In one corner of the pump compartment of the shaft, an air box has been installed. At each level, part of the air is taken out and direct connection is made to the flexible tubing that runs to the breast of the crosscut. These headings have advanced about 300 ft. on each level. In spite of the high rock temperatures, the working conditions at the breast have been kept very comfortable. By having at each working place a number of short lengths, the men can bring the lead piece as close to them as they wish. When the short lengths are all in use, a long length is sent down to take their place. This order of changes is repeated time and again as the work progresses.

In these levels, 10 and 12-in. tubing is used. In its use, we have found that the tension rings that are used in connection with the clamp that grips the wire, and of course the clamp too, are not necessary on the smaller tubing. When they are not used, the clips that are bent around the wire messenger to support the tubing must be carefully tightened.

Tubing in Raises and Stopes

Considerably more care must be exercised in the use of the canvas tubing for ventilating raises than need be taken in crosscuts or drifts. Where the rock temperature is high, it will be found that added advance and the consequently diminished cost will repay amply the time spent in placing and protecting the tubing. In all the vertical portions of the raises, it is found necessary to box the tubing for protection from falling rocks. These boxes need not be air-tight and can quickly be thrown together out of 1-in. material. At the offsets the tubing need not be covered.

The discharge from the top box must be covered with a screen to keep falling pieces from going down the tubing, and it must be especially well protected when blasting.

Being close to a natural current of good air does not always make a good place to work. A stope was started on the 2600 directly over a crosscut which was a main air course of the level. On the first floor the conditions were good, the second floor was a poor place to work in, and the third floor was so hot that but little was accomplished, though neither end of the stope was 50 ft. (15 m.) from the main air course. There being no working on the 2400 to hole to with a raise, natural ventilation was impossible. A No. 4 Sirocco fan with a 20-hp. motor was placed at the crosscut and the air was taken through a 16-in. tube up a manway and turned directly on the men in the stope. This made it a good place to work. Very often stopes such as this must be worked until connections can be made to other levels, and the use of blower fans seems to be the best solution of the problem that such places present.

In one stope with ample connections between levels, a No. 4 fan and 16-in. tubing completely reversed the air currents, with a resulting drop of 15°. This good result was accomplished without causing any apparent ill effect in our other workings.

Direct-current Mounted Fans

Often places are met, in both stoping and development, where artificial ventilation is needed only for a short time, while a raise is being put through or a crosscut or drift is being extended. Such work may take a month or less. Conditions may be normally such that it is impossible to hold men in these places. The short period of time that we need to have a fan blowing, before natural ventilation can be attained, has made us hesitate to put in a concrete foundation. Wood foundations we have tried to eliminate entirely for all electric machinery, on account of fire risk. As motor haulage with direct current is used almost entirely, and as the trolley lines reach almost every part of the mine, we have mounted some No. 2 and No. 3 direct-current fans on trucks. Such fans, mounted

on heavy plates and arranged so that they may be turned to any angle (in a horizontal plane) with the trucks, make a very satisfactory installation for use in these places. One, complete with its auto-starter and the canvas tubing, is run to the place where needed; here it is thrown (truck and all) from the track, or placed on a siding; a wire messenger is strung; connections are made for electric current, and the fan is started with comparatively little work. These fans are moved from place to place and will in a short time save in labor and foundation material the cost of the truck and time of mounting.

The examples that have been given all concern places of considerable depth. A word might be said concerning our northwestern tunnel, where a fan and tubing were used. I hope that my words may in no way detract from the credit due to the foreman in charge for the good work he did. While the rest of the machinery was being installed, it was thought advisable to put up a fan at the portal, and it was but a short time before its need was evident. Three shifts of 8 hr. each were worked and in 3 months' time but one shift missed blasting and that round was made up in the next 8 hr. In November, 446 ft. (136 m.) was driven, December's advance was 477 ft. (145 m.) and in January 510 ft. (155 m.) was made. The work was done with but four men per shift at the breast, two miners and two shovelers.

It is hard to figure out just how much aid the blower fan and tubing afforded in making this advance, but it is safe to say that almost an hour a shift was added to the working day. Sometimes this must have made the difference between getting a round and losing one. It always meant that the round could be a little deeper. Both of these things have their dollars and cents value, whether we can figure the exact amount or not.

Within the last few months, many improvements have been made on the tubing. The first that was sent us from the factory was coated on one side only, had no means of support and an inconvenient and inefficient means of connecting lengths. As shipped today, the tubing is coated on both sides, has a wide top hem in which at intervals of a few feet are grommets and suspension clips, and, at the ends of each section, are coupling rings which make its installation very simple, rapid, and satisfactory.

In General

Our experience with canvas tubing has now extended over a period of more than a year. It has been tried in all kinds of working places that we meet, and we feel that in every case we have been amply repaid for the installation. We are convinced that it is in every way more satisfactory than the metal tubing and that those who adopt it will not go back to galvanized iron.

The Drifton Breaker*

BY EFFINGHAM P. HUMPHREY,† M. E., UPPER LEHIGH, PA.

(New York Meeting, February, 1918)

THE Lehigh Valley Coal Co. finished the rebuilding of its Drifton No. 2 breaker at Drifton, Pa., in the summer of 1917. The new construction comprises an addition and the complete remodeling of the old breaker. It is of interest to note that the old structure was the first iron breaker erected in the anthracite region.

THE OLD BREAKER

This old breaker was built by the Cross Creek Coal Co., under the direction of the late Eckley B. Coxe, in 1888–89, and was fully described by him in the *Transactions*[1]. The columns were cast iron, 8, 10 and 12 in. square. The floors and partitions in pockets were cast-iron ribbed plates. The struts were cast iron of "H" section; the other members were of structural iron either rolled I-beams or built-up sections. The sizes of the rolled beams varied from 6 to 20 in. deep, while the built-up sections, made of plates and angles, varied from 6 to 63 in. in depth, so that there apparently was no rule to determine the type of section used.

In the remodeling of the old structure, practically everything was taken down excepting the columns and roof, and such beams as were necessary for temporary construction purposes, and, therefore, a close inspection of the old structural members could be made and the effect of the acid water on them could be noted. The cast-iron members were but slightly attacked by the water, while the wrought-iron beams, in the wet places, were corroded almost to failure.

The following are analyses of cast-iron, wrought-iron, and structural-steel samples taken from the old and the new structure.

	Si	S	P	Mn	C
Old part, rolled struct. iron......	0.13	0.06	0.29	0.013	0.17
New part, rolled struct. steel.....	0.03	0.04	0.11	0.240	0.26
Old part, cast iron...............	1.18	0.12	0.93	0.229	
New part, cast iron..............	2.41	0.13	0.72	0.280	

* Presented before the Pennsylvania Anthracite Section, Nov. 24, 1917.

† Asst. Supt., J. S. Wentz Co.

[1] (1890–91), **19**, 398.

The mine water contained 71.79 parts per million of free sulphuric acid and 320.88 parts per million of total sulphuric acid as sulphates.
The temperature of the water was 72° F.

Depreciation of Steel Structures

The depreciation of a structural-steel breaker for dry preparation is unknown, but is estimated at 1.25 per cent., while for a breaker using acidulous mine water during preparation, I estimate the depreciation at 4 per cent., as determined by the life of the steel in the old Drifton breaker, which was 26 years. This figure may be high, for repairs and replacements to broken beams, due to corrosion, were frequently made in the old Drifton breaker. Water-tight construction of chutes and hoppers, to prevent the water from coming in contact with the iron would certainly have prolonged its life, but little or no attention was given to this when the old breaker was built; in fact, very little water was used then as compared with the quantity now required.

An interesting phenomenon was noticed in the effect of the corrosion where wrought and cast iron were in contact in the presence of the acidulous water. In such instances, the corrosion of both pieces was more rapid than separate pieces under the same condition. It may be probable that the action was assisted by a very weak electrolytic action caused by the slight difference in the metals. Slag holes in the castings showed more rapid corrosion than any of the other places, probably due to the same action.

The New Addition

The new addition is a modern fireproof structure built of structural steel with corrugated metal roof and siding, steel window frames, and concrete floors. There are 332 tons of structural steel, or 1.35 lb. per cubic foot of breaker volume, distributed as follows:

	Tons
Columns	67.0
Pockets and beams	192.0
Stairs and treads	8 5
Bracing	16.5
Roof	20.0
Girts	22.0
Miscellaneous, rivets, etc.	6.0
	332.0

The average length of column is 72.5 ft. and the ground area 6730 sq. ft. The cubical contents is 48,792 cu. ft. The roof area is 7400 sq. ft. and the metal sides 18,500 sq. ft. The floors are 3½ in. thick, of concrete laid on deep-rib Hy-rib. The hoppers, chutes, and jigs are of wood,

and waterproofed to protect the iron work from the mine water. The structural steel was painted with two coats of red lead and graphite paint. The arrangement of the jigs along each side of the breaker gives them the maximum amount of light. The machinery and shafting are accessible, and the rope drives are located in one bay, not scattered throughout the addition, as is frequently the case. The building is well lighted throughout and contains 6700 sq. ft. of glass.

The Old Breaker Remodeled

The cast-iron columns of the old breaker were practically the only members re-used. New columns, girts, machinery supports, hoppers, chutes, and stairs, are of wood. Distortion of the old structure and the difficulty of plumbing it prohibited the use of steel except at great expense. The worn-out sheet-metal sides and roof were duplicated, using 16,500 sq. ft. of siding and 5720 sq. ft. of roofing. Its cubical content is 389,000 cu. ft. The window area is 5700 sq. ft.

Preparation

The new plant at Drifton was built under the direction of Paul Sterling, Mechanical Engineer, Lehigh Valley Coal Co., and is designed to prepare 1500 tons of coal in an 8-hr. working day. The author was engineer in charge of the entire remodeling and construction.

The new preparation plan (Fig. 1) required more height than was available in the old breaker; additional height was obtained by using elevators, and the addition was erected without seriously interfering with the operation of the colliery. While the use of elevators to handle prepared coal is not recommended, yet the conditions at Drifton did not warrant the adoption of a plan involving a shut-down, or the expenditure required to replace the entire old breaker by a new and costly one.

The best daily output to date is 1735 tons, and it is expected that the breaker will be able to prepare and load 2500 tons daily. At present, the average dump is approximately 600 mine cars a day, 35 per cent. of this coming from the Lattimer stripping. This coal is of medium quality, one-half being good big-vein coal, and the other half of poorer quality that is mined from a small vein containing about 15 per cent. of divider rock. Three per cent. of the input comes from the Buck Mountain stripping, and is a very poor grade of coal, shaly and full of clay; the remainder of the breaker input is mine coal, hand loaded and of good quality.

The force on preparation is as follows: 1 breaker boss, 1 jig boss, 1 picking-table boss, 1 ticket taker and docking boss, 2 dumpers, 4 pickers on platform, 3 pickers on broken coal, 2 pickers on jig refuse, 2 jig runners,

4 machinery attendants (screen men and roll tenders), 1 breaker engineer, 1 oiler, 1 ropeman, 1 breaker cleaner; total 25 men.

The force loading coal and charged against loading is: 1 loader engineer, 4 loaders, 2 runners; a total of 32 men in the breaker.

One man attends the rock crusher in the breaker, but part of his time is charged against the disposition of refuse. The rock crusher is driven by its own engine, so that it may be independent of the breaker, which permits of refuse disposition after quitting time, a necessary measure because rock may accumulate on the picking head when there is an interruption in the operation of the refuse conveyor.

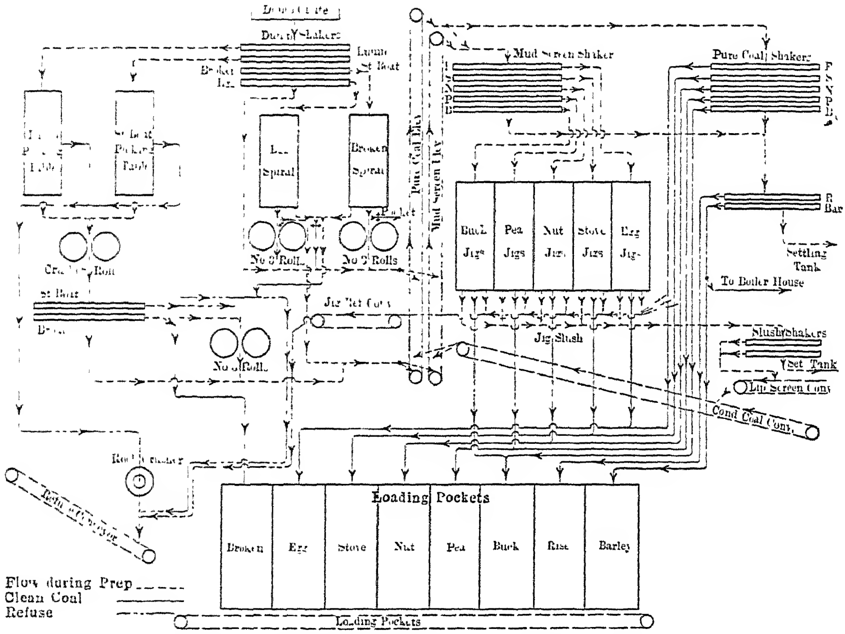

FIG. 1.—NEW SCHEME OF PREPARATION, DRIFTON BREAKER.

METHOD OF PREPARATION

The method of elevating the run-of-mine coal in the remodeled breaker was not changed from that originally devised and installed by Mr. Coxe. There are two hoists, a single barney-plane hoist from the surface for all coal transported over ground from distant openings and strippings, and a balanced gunboat or skip hoist on the slope which connects a dump in the mines with the receiving hopper in the head of the breaker. The gunboat also serves a surface dump, which is used to handle the cars in excess of the barney-hoist capacity. The receiving hopper is large and permits continued dumping during short stops of the breaker. From this hopper, the run-of-mine gravitates to a reciprocating feeder, which

delivers to a bifurcated chute which divides the flow so that it runs onto two banks of mud screen shakers, of four decks each, sizing lump, steamboat, broken, and egg. The first two sizes gravitate to their respective moving picking tables. It is intended that pure coal shall be made in the future, but at present all prepared coal is jigged, and the pickers on the moving tables only "skin" the pure-coal product of impurities. No hand chipping is done, all half-and-half or capped pieces are left on the tables. The picked rock and impurities are thrown into a large chute of sufficient capacity to store a day's run, should any delay or breakdown occur to the refuse-handling machinery. This chute delivers to a No. 9 Gates gyratory crusher which reduces the material to about 3-in. lumps, and delivers it to a refuse conveyor to be conveyed to the rock bank.

The lump and steamboat products from the tables flow to a slow-speed No. 1 roll, breaking to steamboat and smaller, with a small percentage of steamboat oversize. The broken-down material flows to two banks of two-deck shakers, sizing steamboat and broken. The former size is broken down in a slow-speed re-breaker, or No. 3 pure-coal roll, to egg and smaller. The broken is inspected, any impurities being removed by hand picking, and then flows to the main broken loading pocket, or is switched to a separate pocket for use on the locomotive.

When there is no sale for broken, it mixes with the steamboat going to the pure-coal roll. The re-broken product from the pure-coal roll gravitates to the pure-coal elevator feeding pocket, of 20 tons storage capacity, to act as a reservoir in front of the fixed-capacity elevators; and is stored there during periods of fast dumping.

The mud-screen broken and egg is run over anthracite spirals, three for each size. These are adjusted to remove the maximum amount of rock so that one picker on the refuse, from each set of three spirals, can clean the product by hand picking out the pure coal. The refuse from all spirals flows to the rock-handling machinery. The spirals, in addition to relieving the jigs of handling this refuse material, also protect the re-breaker rolls, receiving the spiraled product, as it has been found that rock dulls the roll teeth more quickly than the coal, thereby reducing the roll efficiency and the prepared sizes.

The spiraled mud-screen broken flows to its slow-speed re-breaker, or No. 3 mud-screen roll, which breaks to egg, stove, and smaller. The spiraled mud-screen egg flows to its No. 3 roll, or, when there is a demand for it, the egg is switched around the roll. The entire mud-screen product from both of the No. 3 rolls, also the egg (when not broken down) is mixed in the mud-screen coal elevator feeding pocket, a duplicate of the one for the pure coal.

Two elevators, one for pure and one for mud-screen coal, lift the products from the elevator feeding pockets to the top of the new addition

(Fig. 2). There are four banks of five-deck shakers, arranged parallel. The two outside banks are for pure coal and the inside banks for mud-screen. At present (as already mentioned) no pure coal is made, as it has been found cheaper to remove refuse by jigging. This method of preparation will be continued until the quantity of the run-of-mine is increased to such an extent that it is necessary to make a pure-coal product, or if the quality of the present run-of-mine should change, producing a tremendous quantity of large lumps of pure coal, then the

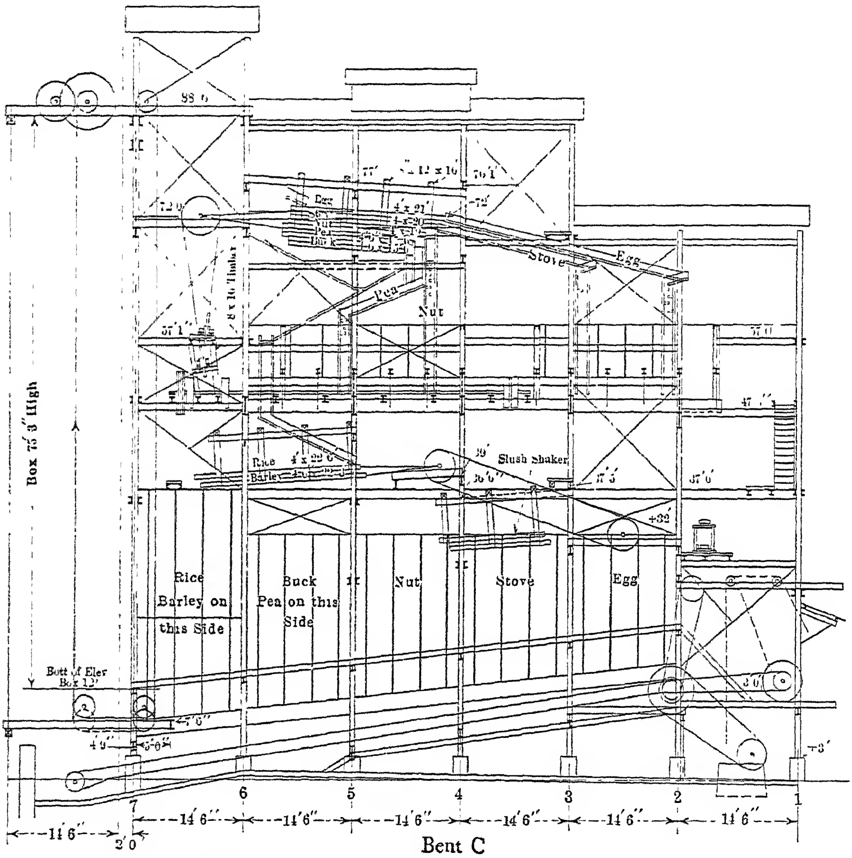

FIG. 2.—LONGITUDINAL SECTION THROUGH BREAKER ADDITION.

hand-picking force will be increased in order to clean the product on the moving tables.

With the present plan, the elevated pure and mud-screen products are dumped into the mud-screen bifurcated chute delivering to the two mud-screen shakers (the outside, or pure-coal shakers, are not operating). These shakers size egg, stove, chestnut, pea, and buckwheat. Each size flows into its respective jig storage pocket. The jig pocket acts as a reservoir behind the jigs, storing up during rush periods and feeding

out when no coal is coming. These pockets are equipped with adjustable partitions, arranged so that the capacity of any one pocket may be increased, by decreasing the capacity of the adjacent one. The partitions are changed to accommodate the quantity of each size made, and thereby increase or decrease the number of jigs on any one size, where it is necessary to handle a greater or lesser quantity of any size, to meet the varying market demands. For example, when breaking down all coal to stove and smaller, no egg jigs are needed; therefore egg jigs can be run on stove, and *vice versa*.

The coal from the jig pockets flows to the jigs. These are equipped with automatic starting and stopping devices, actuated by the weight of coal in the chute, connecting the jig pocket to the jig, and operating a belt shifter through a system of levers. By means of this control, jigs will stop when no coal is coming and the jig pocket is empty, and will start up as soon as the feed starts again.

The clean coal from the jigs gravitates to the loading pockets, while the refuse is conveyed to the refuse-conveyor line. The coal is loaded into cars by a belt conveyor, which system was first used in the anthracite region by the Lehigh Valley Coal Co. The pocket gates differ from those previously used in being located at the end of the chute leading to the belt, instead of several feet up the chute, at the point where the chute enters the loading pocket, thereby reducing the initial breakage resulting from the sudden rush of coal down the chute when the gate is opened, and permitting the use of a lifting check gate rather than a cut-off gate. The latter gate requires more power to operate than the former and was steam operated on previous installations of our company. The latter is opened by the weight of coal against the gate, when the operating chain is raised and is closed by the belt loader operator, who pulls a chain connected to the gate.

The rice and smaller from the buckwheat shakers flows to two banks of two-deck shakers, sizing rice and barley. The material falling through the lower deck flows to settling tanks. The chutes from the rice and barley shakers are arranged so that both or either size may go to its respective loading pocket, or to the boiler-house conveyor line.

The jig slush or hutch product is delivered on a single-deck shaker, the material passing over is conveyed, together with the lip screenings, to a screening storage pocket. The product falling through goes to the settling tanks. Condemned coal is dumped into a hopper connected to the foot of the elevators by a conveyor. This conveyor will deliver to either the pure or the mud-screen coal elevator, by changing a switch in the discharge chute. Coal condemned for impurities can be switched to the mud-screen elevator, while coal condemned for screening can be sent to the pure-coal elevator. The condemned-coal conveyor also handles the lip screenings from their storage pocket. When the pocket

is full, the conveyor is started and operates until the pocket is empty. When it is necessary to make a pure-coal product, the pure-coal elevator will discharge into the pure-coal bifurcated chute leading to the outside pure-coal shakers. The sized coal from the shakers will mix with the clean coal from the jig and flow to the loading pockets.

Breakage.—No controls to handle the coal in the old breaker have been installed, as usually the product is unsized and the breakage is practically nil. Abrupt turns and high drops are avoided as much as possible.

Elevator breakage is minimized by proper feed at bottom and proper discharge at the top. In the addition, White chute controls are used where thought necessary and vertical stepped telegraphs for lowering into jig and loading pockets. Spiral chutes are installed to lower pure coal. A movable pocket-filler chute is used on broken. Loading gates are as previously mentioned. The adjustable boom on the end of the belt conveyor, with curved chute, prevents a high drop into cars, and assures a fairly uniform distribution of any screenings through the loaded car.

Breaker Water.—Water for preparation is required in the addition only. It is pumped direct from the mines to a 6000-gal. wooden storage tank, placed in the top of the old breaker. A cast-iron distributing main is connected to the bottom of the tank; branch lines run from this main: (1) to the pure-coal and mud-screen shakers; (2) to the jigs; and (3) to the lip screen. Outlets are placed throughout the breaker for hose connections for washing down, and for fire; cut-out valves are placed on each branch line. At present, an outlet is furnished for each jig, but this is to be changed to an automatic jig-filler trough. This arrangement consists of a trough running back of the jigs with a 3-in. (76.2-mm.) cast-iron connecting pipe from the bottom of the trough to each jig. A connection will be made from the distributing main to the trough, with an automatic float valve on the end arranged to maintain a constant level of water in the trough. The trough will be filled with water up to a height to balance the water in the jigs through the connecting pipe. If the height of water in any jig falls below the proper level, water in the trough will flow into the jig and the automatic float valve will open and the water fill the trough until the balance is reached, when the automatic float valve will close. This arrangement maintains a constant water level in the jigs, and results in better jigging due to the uniform conditions. It should also result in a saving in the quantity of water used by the jigs, as compared to the amount used when inefficiently controlled by hand.

Machinery.—The machinery in the old structure was the subject of an article by E. B. Coxe,[2] 1890. It is interesting to note the changes in

[2] *Trans.* (1890–91), **19**, 398.

the methods of preparation. The more modern plants have more machinery and less men for the same tonnage even though the quality of the coal in many cases is poorer.

In the Drifton breaker, shakers are made of 3 by 6-in. (76.2 by 152.4-mm.) wood sides with 3½ by 3½ by ⅜-in. (88.9 by 88.9 by 9.52-mm.) cross-frame angles, suspended by 1 by 6-in. (25.4 by 152.4-mm.) hanger boards. They are driven by 3-in. throw eccentrics at 150 r.p.m. connected to the shaker by 3 by 6-in. Parrish flexible wood arms. The shakers are 4 ft. 0 in. (1.22 m.) and 4 ft. 6 in. (1.37 m.) wide by 15 ft. 0 in. (4.57 m.) to 24 ft. 0 in. (7.32 m.) long.

Rolls are of the slow-speed type, 36 by 36-in., compound geared with cast-iron chilled teeth built up in segments. The peripheral speed is 300 ft. per minute and they have a capacity of about 300 tons an hour.

The jigs are the Simplex pan type, running at 137 r.p.m. with automatic slate gate and automatic starter. There are 20 jigs placed back to back in two rows of 10 each, facing opposite sides of the breaker, affording excellent light for refuse and coal inspection. At present there are five jigs for egg, four for stove, four for nut, three for pea, and two for buckwheat.

Jigging results for the month of October, 1916 (189.5 working hours), were as follows:

Size	Tons	Tons per Hour per Jig
Egg	5,212	5.5
Stove	7,342	7.7
Nut	5,152	6.8
Pea	2,038	5.4
Buck	3,773	9.9

The delays for "no coal" for the same month were 24¼ hr., but these are not considered in the above results.

The average percentages of coal and chipped coal in the refuse for the same month were as follows:

Size	Per Cent. Coal	Per Cent. Chipped Coal	Average Per Cent. Pure Coal for Prepared Sizes	Average Per Cent. Pure Coal, all Sizes
Egg	1.00	0.89		
Stove	1.12	0.50	1.14	
Nut	1.50	....		1.25
Pea	2.90	....	3.38	
Buck	3.75	....		

The only hand pickers on refuse from the jigs were two boys on egg coal. During that month, one car of chestnut was condemned for stained coal and one-half car of chestnut for screenings.

The number of tons per jig per hour for the best day (1735 tons total), with no coal condemned and 1 hr. delay for "no coal" was as follows:

Size	Tons per Hour per Jig
Egg	7.4
Stove	7.5
Nut	11 7
Pea	11 0
Buck	14.7

On this day there were four jigs for egg, six for stove, five for nut, two for pea, and two for buckwheat.

All the conveyors have 6 by 18-in. (15.2 by 45.7-cm.) flights with 9-in. (22.8-cm.) pitch Keystone chain. The elevators have 22 by 25 by 12-in. buckets at 18-in. centers with two strands of 9-in. pitch heavy pattern Keystone chain. The elevators travel 90 ft. (27.4 m.) per minute and have a capacity of 200 tons an hour.

The moving picking tables, 4 ft. 6 in. (1.37 m.) wide, are of the overlapping pan type and run at about 30 ft. a minute. Each table is equipped with a friction clutch for starting and stopping and a moving apron discharge chute.

The breaker engine is an 18 by 36-in. double reversible Corliss valve type, non-condensing, running at 100 r.p.m. belted to the main line shaft by a 24-in., 10-ply rubber belt. The average i.hp. is 272 loaded and 165 i.hp. when running light. This power is distributed approximately as follows:

1	Feeder	2
2	Banks dump shakers—8 single shakers	16
1	Crusher roll	12
2	Tables	8
2	Banks pure-coal shakers—4 single decks	8
2	Sets No. 3 re-breakers	18
2	Elevators	65
2	Banks shakers, two of 2 decks, two of 3 decks	20
18	Simplex jigs	72
3	Sections of refuse lines—174 ft	19
2	Banks rice and barley shakers—4 single decks	8
1	Bank slush shakers—2 single decks	3
1	Condemned-coal line—200 ft	29
		272

The above figures are the i. hp. for each machine at the engine, and include the friction of line shafts and drives.

Several of the drives from the main line shaft are equipped with friction clutches. These drives are arranged so that combinations of machines may be operated while other combinations are momentarily stopped for attention or repairs. Generally speaking, all rope sheaves are 60 in. (152.4 cm.) in diameter for 1½ in. (38.1 mm.) manilla rope, and belt pulleys are 48 in. (121.9 cm.) diameter. In the addition, rope drives are used exclusively between the main line shaft and the main counter shafts.

The feeder is built like the shakers, but is fitted with blank plates, and is driven by adjustable-throw eccentrics in order to vary the feed.

The loading belt conveyor is a 36-in. (91.4-cm.) by 6-ply ⅛-in. (3.17-mm.) rubber-covered belt, running on Robins troughing and return idlers. The speed ranges from 300 to 500 ft. per minute, according to the size of the coal handled, and is adjusted by hand control of the 8 by 10-in. driving engine; the larger the size of coal, the slower the speed.

Steam Heat.—A gravity return system is used, the returned condensed steam being wasted. The pipe radiator coils consist of 15,300 lin. ft. of 2-in. pipe, or 155 cu. ft. of breaker contents per foot of 2-in. pipe. Exhaust steam from the breaker engine is used when operating; live steam at other times.

Method of Erection

The addition was erected over the old loading tracks, and clearance was provided for admitting the cars through the addition during the operation by omitting some of the structural steel. A new loading track was built in front of the addition, and the loading belt conveyor erected. New holes were cut in the bottom of the loading pockets in the old breaker and chutes were run to a common point to deliver to the loading belt conveyor. When this work was completed, the change from the old method of loading to the present one was made over a Sunday. This did away with the old loading track and permitted the completion of the addition without interruption.

In the meantime, as the addition was being finished, one elevator was installed and as soon as the new part was complete, by a temporary chute arrangement the coal was carried into the addition and prepared there, thus allowing the removal of all machinery in the old part except the rolls, dump bars, and picking head. These rolls were set to pass nothing larger than broken, and by putting an extra broken deck on the shakers, in the addition, this broken was removed and cleaned by hand picking and run to a temporary loading pocket.

New rolls, tables, shakers, and elevator were then placed in the old breaker and gradually put into service. The remodeling was finally completed without any serious loss in production due to erection delays.

During construction, much overtime and Sunday work were necessary to change and install the temporary chutes for connecting old work with new, which usually had to be torn out or replaced by permanent construction as the work proceeded. The greatest difficulty was found in supporting old machinery in the old structure, because of the corrosion of steel beams, which in many cases were held in place by old chutes, hoppers, etc. When these were removed, the steel member frequently fell out or came loose, adding to the danger. By safety-first methods at all times, the job was completed without serious accident of any kind.

Economy of Electricity over Steam for Power Purposes In and About Mines*

BY R. E. HOBART,† LANSFORD, PA.

(New York Meeting, February, 1918)

THE development of the Hauto power plant and the claims made by various engineers that electricity was more economical than steam for power purposes in and about the mines, led the Lehigh Coal and Navigation Co., in 1911, to conduct a test to ascertain the consumption of power used by a large steam hoisting engine. The question being one on which no reliable information could be found, and the opinion of various engineers differing to such an extent, it was decided that a test under actual operating conditions was necessary. This was arranged for at one of the collieries. The engine selected was a 30 by 60-in. (76.2 by 152.4-cm.) piston-valve engine of modern type, and comparatively new.

The boiler plant from which the hoist received its power was about 600 ft. (182 m.) from the engine, the latter being fed by a 10-in. (25.4-cm.) steam line insulated with magnesia pipe covering. Two batteries of the boiler plant, aggregating 1200 hp., were cut off and fed into a separate steam line leading direct to the hoist engine. Steam auxiliaries, consisting of feed-water pump and blowers, were fed by the boilers in test, and their consumption charged against the hoist. A barrel weighing device was installed, as it was felt that this would be the most accurate way of determining the consumption of water. The fuel, No. 3 buckwheat, was carefully weighed, and every precaution was taken to make the test accurate in every particular.

The test was run for 1 week, or a total of 168 hr. A record was kept of the number of trips hoisted or lowered, and continuous indicator cards were taken. One particular set of cards was taken with the hoist operating balanced, and also with the hoist operating with no counterweight other than the empty cage, the coal in the car being weighed. The speed of the hoist was taken by means of a graphic recording instrument which registered the number of revolutions every 5 sec. From this record, speed-time curves were plotted.

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* Originally presented at a meeting of the Pennsylvania Anthracite Section, on Nov. 24, 1917.

† Mechanical Supt., Lehigh Coal and Navigation Co.

The test was divided into two periods: working and idle time. The hoist did not operate between the hours of 5.30 p. m. and 6.30 a. m., nor from 3.30 p. m. Saturday, until 6.30 a. m. Monday morning. The actual working time, therefore, was 64 hr., and the idle time 104 hr. for the week. The total weight of coal used in idle time was 108,075 lb., while the coal used in working time was 119,950 lb. From these figures, the amount of coal consumed per hour to cover stand-by losses would be 108,075 ÷ 104 = 1038 lb. of coal per hour.

During the week, 1705 cars of coal were hoisted from a depth of 581 ft. A tabulation of test results is shown in Table 1.

TABLE 1.—*Tabulation of Results, Hoisting by Steam*

Depth of shaft, ft.	581
Weight of coal per car, lb.	8,960
Coal used during 104 idle hours, lb	108,075
Coal per hour idle, lb.	1,038
Trips during week.	1,705
Actual time used in hoisting, sec., 1,705 × 25	42,625
Actual hours hoisting 42,625 ÷ (60 × 60).	11 82
Seconds during week.	604,800
Seconds idle during week.	562,175
Idle hours.	156.2
Coal used during idle time, lb., 156.2 × 1,038.	162,135
Coal used during hoisting, lb., 228,025 − 162,135.	65,890
Coal used per trip, lb., 65,890 ÷ 1,705.	38 6
Horsepower-hours per trip, $\frac{581 \times 8{,}960}{33{,}000 \times 60}$	2 63
Coal per horsepower-hour, lb., $\frac{38.6}{2\ 63}$	14.70

From these results, it will be noted that to the 104 idle hours, representing the period when the hoist was not operating, must be added the idle time occurring between hoists during the operating period, which makes a total of 156.2 hr., the actual hoisting time being only 11.82 hr. in the week. From these surprising results, the Lehigh Coal and Navigation Co. felt that it would be advisable to use electric power at the new operation to be developed at No. 11 shaft.

CONDITIONS FOR ELECTRIC HOISTING

It is a well-known fact, in the anthracite region, that the working time of a coal hoist is only from 8 to 9 hr. in a day, the night hoist being intermittent. At the time the test was made very few electric hoists of this capacity were in operation, and most of the larger ones had either the Ward-Leonard or Ilgner system of control, the only large induction hoists being in South Africa. Various hoist engineers were consulted on the different types of hoists using alternating current. Propositions were submitted on the Ward-Leonard and Ilgner systems, as well as on the induction-motor type.

All these hoists have their good and bad features. The Ward-Leonard system consists of a motor-generator set in which an alternating-current motor is directly connected to a direct-current generator, which generator furnishes power to a direct-current hoist motor. The Ilgner system also consists of a motor-generator set, which drives a direct-current hoist motor, the generator being separately excited. By means of a fly wheel and slip regulator, the load peak on the power system is practically eliminated. The other type of hoist is driven with an induction motor, with a polar-wound rotor to permit of the addition of external resistance to the rotor direct.

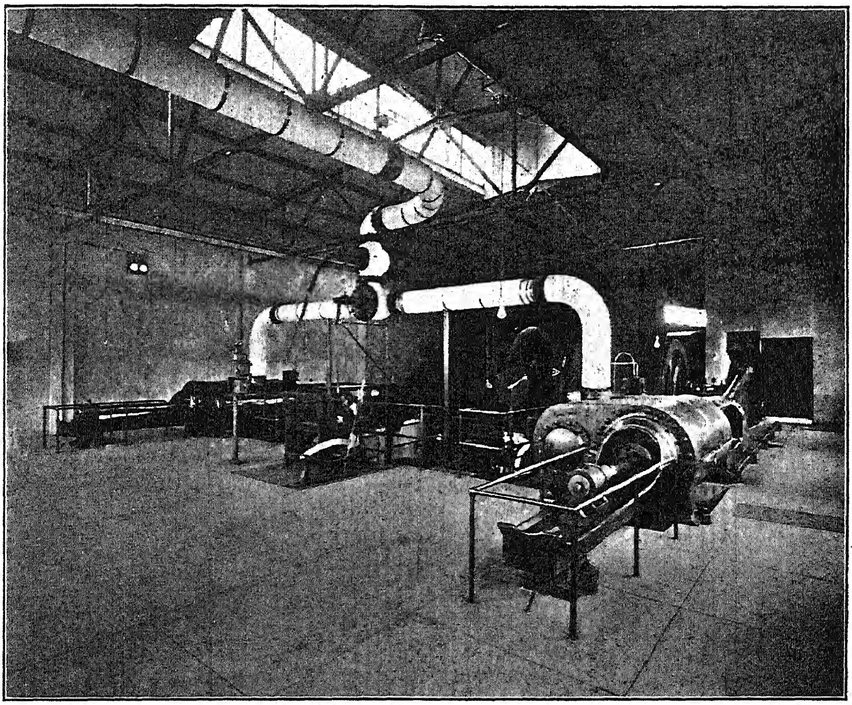

Fig. 1.—Steam hoist, 30 in. by 60 in., Lehigh Coal and Navigation Co.

The lift at No. 11 shaft was 266 ft., and the desired number of cars to be hoisted per hour was 120. This short lift and the number of cars per hour would mean numerous peaks, which from the brief description given of the different systems might make it appear that the Ilgner system would have been the better one to use. However, when it was considered that the working day at that time consisted of 9 hr., with occasional hoisting during the remaining 15 hr. of the day, and with frequent stoppages for various reasons during the working time, it will readily be seen that the generator set would be operating continuously, whereas the actual work done by the hoist would be very little. The other disad-

vantage of the Ilgner system is its high first cost, the hoist costing about 60 per cent. more than an induction hoist.

For these reasons, it was decided to use a slip-ring induction-motor system. Its disadvantages of poor efficiency, low power factor, and high load peaks in starting were offset by the fact that when the hoist is not working, no current is used for the hoisting system excepting the small amount necessary to run the pump for the liquid rheostat, which may be shut off at the will of the operator.

At all the company's operations, synchronous converters are used in

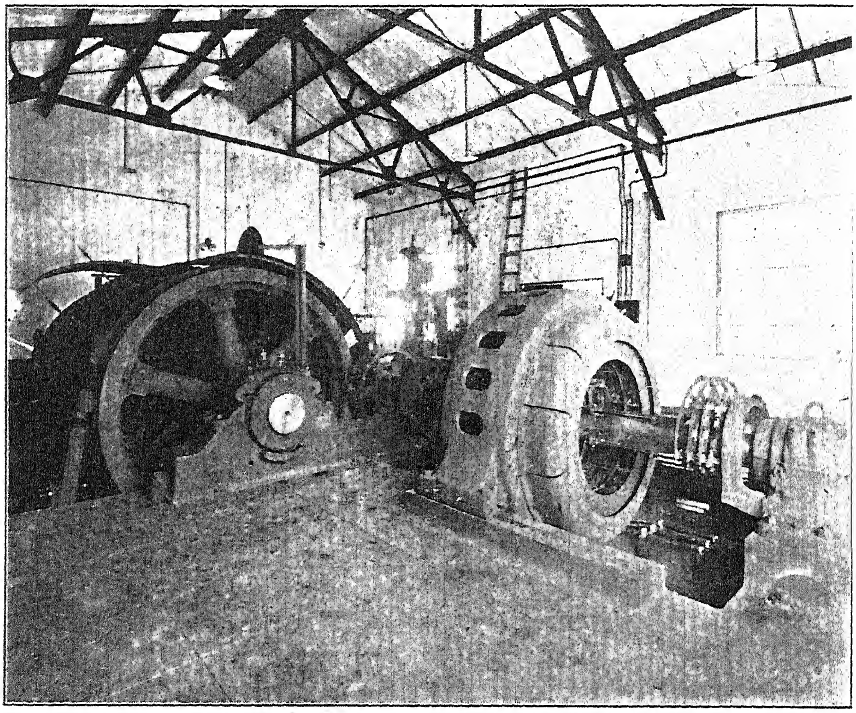

FIG. 2.—ELECTRIC SLIP-RING INDUCTION HOIST, NO. 11 SHAFT, RAHN COLLIERY.

connection with the mine haulage. It was found that there was sufficient converter capacity connected to the supply line to permit of a great deal of power-factor correction.

The next important feature connected with this hoist was to design and make a proper control system. The usual control for electric hoists up to that time consisted of a slow-down device at a predetermined point in the travel, or a device that would automatically operate the controller and apply the brake at a predetermined point. The overwind features were also included.

From experience with steam hoists, it was felt that this type of control would not do for electric hoists, on account of fluctuating loads. Very

frequently loaded cars are hoisted without balance, and loaded cars are lowered at various times, and, what is more important, from 75 to 100 trips a day are made for raising or lowering men. To meet these varied conditions, the company insisted that the following features should be embodied in the control of this hoist:

1. Hoist must not over-travel in either direction.

2. It must be impossible for the operator to start hoist in wrong direction at either limit of travel.

3. Hoist must not back away, due to failure of power or overload.

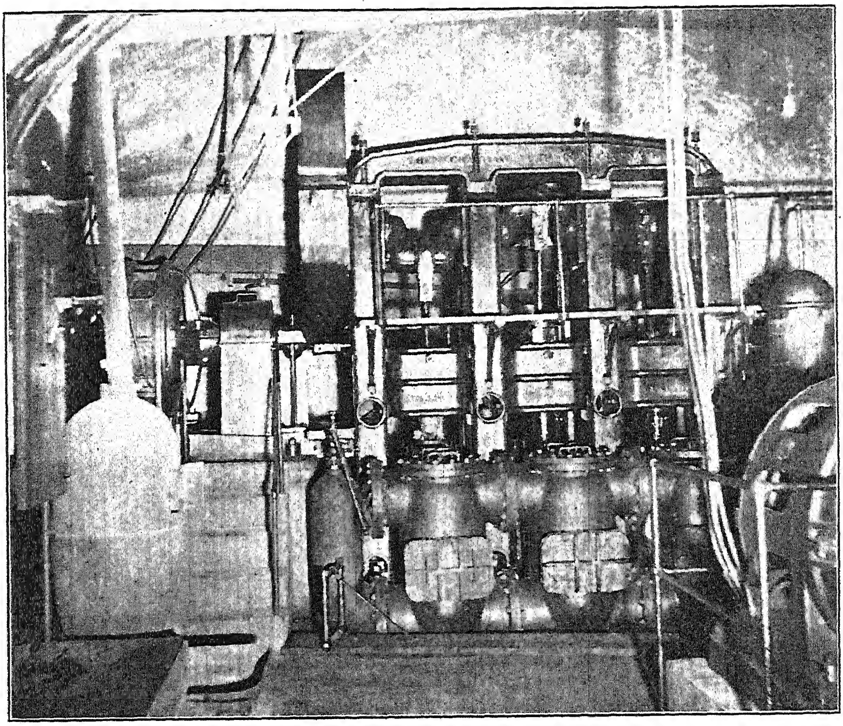

Fig. 3.—Triplex pump, No. 11 shaft, Rahn colliery.

4. Protection must be provided against overspeed, due to any cause whatever in any position of travel.

5. Emergency brake must set and power be interrupted if operator fails to retard hoist approaching landings. This value to be graduated and to be adjustable to meet conditions.

6. Hoist must not start return of power if operator has carelessly left lever in "on" position.

7. If control circuits become grounded, hoist must stop.

8. If operator fails to keep power brake in proper adjustment, emergency brakes must set and power must be interrupted, to remain so until operator has readjusted brake.

9. Hoist must be brought to rest and brake applied on loose drum before clutch can be disengaged.

10. It must be impossible to release brake on loose drum while clutch is disengaged.

11. Pawl must be provided, interlocking with clutch engine lock, this pawl to engage in loose drum before clutch can be released.

12. It must be impossible to operate hoist unless clutch is full "in" and locked.

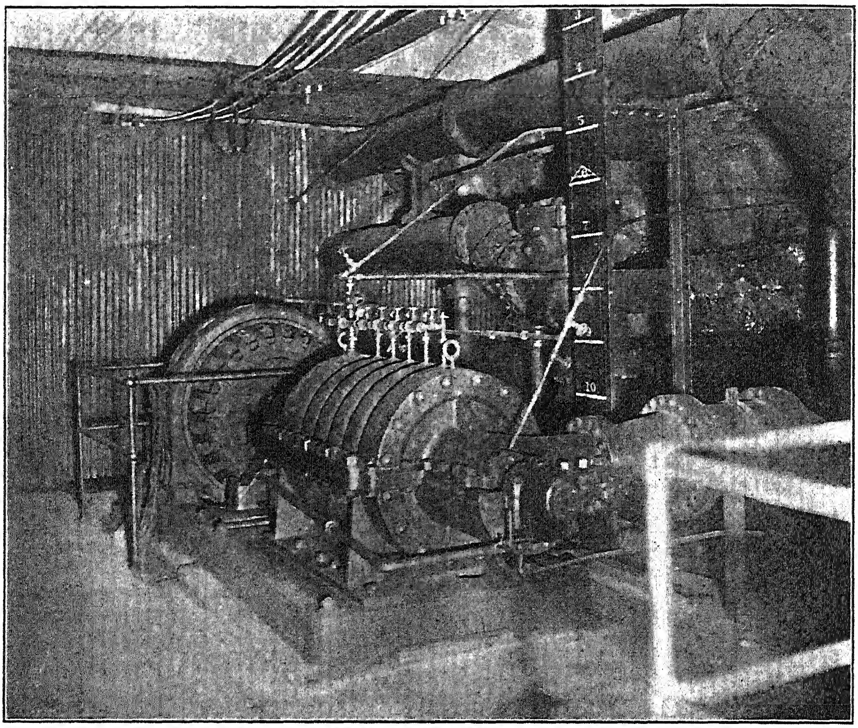

FIG. 4.—CENTRIFUGAL PUMP, 3000 GAL. PER MIN., No. 11 SHAFT, RAHN COLLIERY.

13. Air reservoir must not be drained by emergency stopping of hoist.

14. There must be no delay in operation of hoist due to emergency stopping.

15. It must not be necessary for operator to call assistance in case of emergency stop, over-travel, or otherwise.

16. For operating hoist, multiplicity of levers must be avoided; two will be allowed, *viz.*, brake and control.

17. Hoist operator must not be endangered by flying levers in emergency stopping of hoist.

18. No safety features must be dependent on the will of the operator.

19. Switch must be provided on operator's platform for an emergency stop, if necessary.

20. Travel limits and speed range must be easily adjustable.

21. Current input and acceleration of hoist motor must be governed automatically.

22. Hoist must start from rest gradually without excessive jerks and come to rest smoothly, and must be under control of the operator at all times.

23. The speed of the hoist must be varied by cutting the resistance into or out of the rotor circuit. The rheostat must be of the liquid type and of ample capacity to meet all operative conditions.

All the foregoing features were met in every particular, and it will be found that this type of control for slip-ring induction motor hoists has been made standard by the larger hoist manufacturers.

This hoist was placed in operation on Apr. 16, 1915, and to date has operated with no delays and very little up-keep. During 2½ years, the only repairs necessary to keep the hoist in operation have been a few contact tips for the reversing switches, and packing for the brakes and rheostat pump. The average power used for hoisting a car of coal 266 ft., including line and transformer losses, is 2.59 kw.-hr., which at 8 mills per kw.-hr. amounts to $0.0207 per car, the average weight of coal in the car being 8960 lb.

In connection with the electrification of the hoist, it was decided to electrify both inside and outside the mines. The electric haulage system was already installed inside, but the fans, pumps, and air compressor were steam driven. The fan, which was situated on Sharpe Mountain, was about 100,000 cu. ft. per min. capacity, being driven by an 18 by 36-in. slide-valve engine. The hoisting engine and air compressor were situated near the fan and close to the boiler plant. The development of the new No. 11 shaft allowed the abandonment of the 30 by 60 hoisting engine, as the new electric hoist would operate from the same level as the steam hoist.

In place of the 900-cu. ft. per min. steam-driven air compressor, we erected one of 1500-cu. ft. per. min., electrically driven by a 250-hp. synchronous motor. A 200,000 cu. ft. per. min. fan, driven by 150 hp. slip-ring induction motor, was installed to take the place of the steam fan, and a small steam plant was built for heating purposes.

Electric Pumping Installation

The steam pumps were located in a pump house south of the bottom of the old No. 11 shaft. As this shaft was to be abandoned, it might be interesting to explain the various features of the electric pump installation in the mines. No detailed figures are available on the steam costs of operating the mine pumps, as at that time separate costs for the dif-

ferent units taking steam from the central boiler plant were not kept. The old pumping plant consisted of one 42 by 20 by 72-in. duplex pump, and two 16 by 48-in. single pumps. At various times, in flood seasons, it was necessary to install water tanks in the coal shaft either to prevent drown-outs or to hoist the water from the mine in case of a drown-out.

The sump for the old pump house was situated about 50 ft. south of the old shaft, so it was decided to drive a small sump tunnel from the old sump into the shaft sump. The old sump was also extended westward about 300 ft., making the opening into the sump on a pitch, so that a car could be run into the main sump for cleaning purposes. One 1500-gal. per. min. triplex, one 1500-gal., and two 3000-gal. all-bronze centrifugal pumps, were ordered for this pump house. The triplex and the 1500-gal. centrifugal pumps were placed south of the shaft, and the two 3000-gal. centrifugal pumps were placed north of the shaft. The tail pipes of the 1500-gal. and the two 3000-gal. centrifugal pumps were run into the shaft sump, while the tail pipe of the triplex pump was run into the main sump. A ditch of large capacity was made on the west side of the pump house, entering into the main sump. Gates were installed to allow the water to be diverted into the shaft sump, if necessary, and a gate was installed in the sump tunnel, which dammed off the main sump from the shaft sump. By this method, it is always possible to clean either sump, and it is not necessary to wait for a dry season, with the added expense of installing dams for this necessary cleaning.

All of the centrifugal pumps are horizontally split, being all bronze, with a full-load speed of 725 r.p.m. The reason for specifying this low speed was that the mine water is acidulous and gritty. All pumps are hydraulically balanced, none of them depending upon thrust bearings.

A very important thing to consider in the specification for a centrifugal pump, is to have a proper metal for acidulous water. The specification for the bronze in these pumps was 75 per cent. copper, 15 per cent. lead, and 10 per cent. tin. All screws, washers, and dowel pins should be eliminated from the seal rings and diffusion vanes. In fact, it is believed better to buy pumps without diffusion vanes, as this part of the pump is very apt to give trouble. I do not approve of labyrinth rings for mine pumps. The seal rings should be wide, straight rings, the one on the impeller being shrunk on, the stationary ring being held from turning by a tongue resting on the bottom split of the casing.

It is a question whether the hydraulically balanced pump will operate under all acid conditions. However, the 8-in. and 10-in. 6-stage pumps operating in No. 11 shaft have not given any trouble in this respect since they were placed in operation. The cost for operating these pumps, including transmission line and transformer losses, on a 266-ft. lift, is 1.545 kw.-hr. per 1000 gal., which, at a rate of 8 mills per kw.-hr. amounts to $0.012 per 1000 gallons.

Total Saving by Electrification

When operating the old boiler plant at No. 11, which furnished steam for the No. 11 shaft hoisting engine, one steam fan, one 900-cu. ft. air compressor, the inside pumps, and steam heat, the cost of the boiler plant for the year April, 1914, to April, 1915, was $46,992. This figure included the cost of fuel and handling, wages of firemen and ashmen, maintenance of boilers and pumping of water for the boilers. During the same time, the shaft produced 343,665 tons of coal, or a steam cost of $0.137 per ton.

For the year November, 1916, to November, 1917, the electric power cost was as follows:

Hoist	$3,300.16
Fan	3,270.63
Air compressor	8,845.39
Pumps	6,174.08
Total	$21,590 26

To this figure should be added the cost of the heating plant, making a total power cost of $30,290.26. During this period the shaft produced 435,073 tons, with a power cost of $0.0696 per ton. This shows an actual saving per annum of $16,702, but as the use of electricity permitted more efficient work and less loss of time from repairs, drown-outs, etc., the tonnage hoisted increased from 343,665 to 435,073, and the cost of power per ton produced decreased from $0.137 to $0.0696, a saving of $0.0674 per ton, which for the output of 435,073 tons amounts to $29,149 per annum.

DISCUSSION

Karl A. Pauly,* Schenectady, N. Y.—We are deeply indebted to Mr. Hobart for a record of the actual experience of the Lehigh Coal and Navigation Co. with electrification.

One of the essential features of this test is that it was made under actual operating conditions. In one of the western mining districts I was once discussing the electrification of a large hoist with a mining operator, who told me that they had made a very thorough test and that the results were such as to indicate that electrification was not warranted. When questioned regarding the test, he said that they had called on the mining college in the Territory for assistance, and one of the instructors and a group of students had made the test. They first cleaned the boilers and then operated them at a continuous load to get the evaporation, and used the maker's guaranteed steam consumption of

* Electrical Engineer, General Electric Co.

the hoisting engine as a guide in estimating the coal consumption under actual hoisting conditions. Such a test is absolutely valueless. The efficiency of the boilers is affected by the intermittent demands for steam. The standby losses, as indicated by Mr. Hobart's paper, are quite equal to the actual fuel consumption required to do the work. Also, very frequently, the cost of repairs is either omitted or underestimated in comparing the engine with the motor-driven hoist.

One noticeable feature of Mr. Hobart's tabulation is that there is no mention of steam consumption. Intentionally or otherwise, the steam-hoist builders have befogged the question by making a great point of the steam consumption of hoists. The operator is not at all concerned in steam consumption; it is the actual cost of operation that he is interested in, and it is a comparison between the cost of operation of the two systems, all factors being considered, that should determine the choice. The steam consumption, or its determination by test, is only one step in the problem of estimating the fuel consumption, which, in an actual installation, can be directly measured much more accurately than estimated, as was done by Mr. Hobart.

Mr. Hobart has also mentioned several types of hoists. The choice of the drive for a hoist, as with all similar engineering problems, must be made only after a very careful study of all the conditions affecting the problem, but there are a few general principles which govern the selection. No matter how efficient an induction motor may be, if the power plant is not large enough to take the peaks, it cannot be used, or if your power contract is such that the peak penalization more than offsets transformation losses with the flywheel motor-generator set, the Ilgner system should be chosen. Where the Ilgner system is required, an induction-motor auxiliary may be used, as has frequently been done in some of the western coal mines, for taking care of the night hoisting, permitting the shutting down of the flywheel set during the night. In general, however, where the power system is large, as at Mr. Hobart's plant, the induction motor on the hoist will work out to better advantage. Where automatic hoisting is to be done, the direct-current motor, with Ward-Leonard control, should always be used.

Mr. Hobart has brought out another point in favor of the electric hoist, which is frequently lost sight of, namely, maintenance and repairs. The maintenance and repairs of an electric hoist are almost negligible as compared with the corresponding items for a steam hoist.

Mr. Hobart has also alluded to a point which I have made a great many times: if you are going to electrify, electrify completely; otherwise the effect will be simply to increase your cost. At this same western camp referred to above, I saw an induction motor-driven air compressor which had been shut down to change back to steam power. Since it was

one of our motors that was involved, I took particular interest in the reason for the change, and was informed that the addition of the motor to the compressor simply increased their total operating cost by that much, as the steam cost remained the same. That would naturally be expected, because the most inefficient load on the boiler plant, the one that is the cause for the consumption of the most coal, is the hoist. The power salesman, who was anxious to get a large revenue with a small installed capacity, picked the continuous load (compressor) and avoided the intermittent load (hoist); hence, the boiler costs went on just as before, and to those costs was added the cost for power for driving the compressor.

Graham Bright,* East Pittsburgh, Pa. (written discussion†).—The paper presented by Mr. Hobart is most remarkable in that it is the first time any definite or reliable data, based on actual facts, have been submitted by any person who has been in a position to furnish such information on the comparative costs of steam and electric operation. Both consulting engineers and manufacturers of electrical equipment have known for some time that there would be considerable saving by substituting electricity for steam in and about coal mines, but it is safe to say that had they made claims to any such saving as shown by the tests recorded in Mr. Hobart's paper, the claims would have been given scant consideration.

Mr. Hobart states that the coal used per trip was 38.6 lb., based on the coal burned under the boilers during the hoisting period. If we consider the coal consumed during the entire time, then the coal used per trip would be 134 lb., and if we assume that this coal is worth $1 per ton, 134 lb. would be worth about 15 c. The cost of electric power when hoisting from the 266-ft. level was about 2 c. per trip. Allowing for the greater depth of shaft when hoisting with steam, the cost of electric hoisting from the same depth should not be over 4 c. per trip. The actual value of the coal is therefore nearly four times the cost of power when hoisting by electricity.

Mr. Hobart gives some very excellent reasons why the induction-motor hoist was used in preference to the Ilgner system, using a flywheel motor-generator set. The principal reason why the Ilgner system is used so much in the West is that the power conditions are such that it becomes highly advantageous for the mine operators to use flywheel hoisting equipments. The power system of the Lehigh Coal & Navigation Co. is, however, of sufficient capacity to permit the use of an induction motor without serious disturbance. The only other questions

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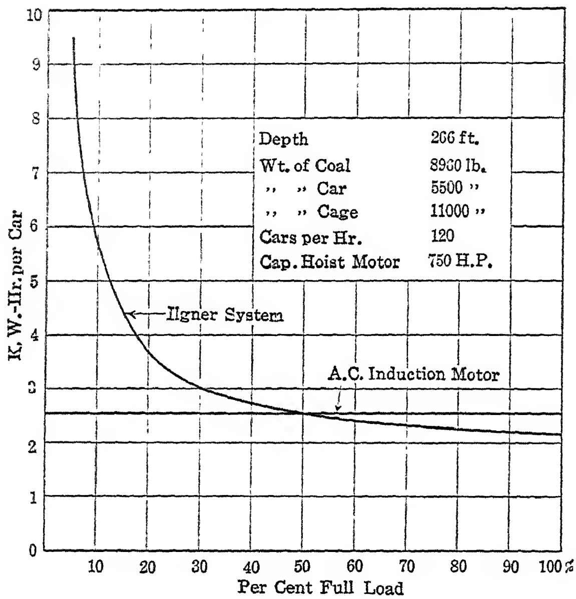
* Engineer, Westinghouse Electric and Manufacturing Co.

† Received Feb. 15, 1918.

then involved were those of first cost of the equipment and the power consumption.

The first cost of the Ilgner system, in many cases, is greater than that stated by Mr. Hobart, while the power consumption depends entirely upon the percentage of time during which the flywheel set is operating while the hoist is idle I am submitting a curve which shows very clearly that Mr Hobart used good judgment in selecting the alternate-current induction motor. This curve shows the power consumption in kilowatt-hours per trip for both the Ilgner system and the alternate-current induction-motor hoist The power consumption of the induction motor is independent of the number of trips made in a given time. The power



consumption of the Ilgner system, however, depends on the rate of hoisting, and shows that when hoisting at 100 per cent. capacity, with no delays other than the usual caging period, the power consumption is about 15 per cent. below that of the induction motor. When operating at less than 100 per cent. output, the power consumption per trip gradually increases, and at 50 per cent. of the full capacity, the power consumption is the same as for the induction-motor hoist. The power consumption increases very rapidly at the lighter loads, due to the constant loss in the motor-generator set, which, in this case, would be about 70 horse-power.

Out of a total of 168 hr. for the week, the hoisting period was 64 hr. Out of this 64 hr., the hoist was in actual operation 11.82 hr., which is 18.5 per cent. If the Ilgner system were used, the flywheel set oper-

ating for 64 hr. and the hoist for 11.82 hr., it will be seen from the curve that the kilowatt-hours per trip, based on all-day operation, would be about 4, which is about 60 per cent. greater than that required by the alternate-current induction motor. From this, it will be seen that if the Ilgner system had been installed they would not only have increased the fixed charges, due to greater cost of the Ilgner system, but would also have had to pay a power bill about 60 per cent. in excess of that obtained with an alternate-current induction-motor hoist.

The figures given at the close of Mr. Hobart's paper, showing the costs for an entire year with steam operation and with electric operation, are very interesting; I believe that the indicated saving per annum of $29,149 would be even greater if account were taken of the fact that both labor and material for the year between November, 1916, and November, 1917, cost considerably more than during the year from April, 1914, to April, 1915.

W. H. Blauvelt, Syracuse, N. Y.—To one who does not know much about coal mining but is very much interested in fuel conservation, the figures given on coal saving are most interesting. It is quite apparent that if one has several operations, the distribution of the peaks would cause an immediate and important saving; but as I understand this paper, Mr. Hobart's figures apply to one mine only, and I wish to ask what the reason is for diminishing the coal bill by one-half? It is clear that for running compressors or pumps at distant points in the mine, electricity would be very much cheaper than steam, but as the hoist is the principal power consumer to which Mr. Hobart's data apply, I wonder if the power machinery he had in use before electrification was of indifferent efficiency.

R. E. Hobart.—Our steam-driven pumps at this mine were no better and no worse than the average steam pumps in use at various anthracite mines. They were not compound or triple-expansion condensing pumps, as pumps of that type require a considerable amount of up-keep on the condensers, due to the necessary use of acid cooling water. The use of steam pumps in the mines further necessitates a considerable amount of mine up-keep, which should be charged against the power cost, but is charged against the mine operation. The cost of repairs to timbering, either in a shaft or a steam-pipe way, is considerable, due to the heat from the pipe and steam escaping from joints. Our experience has been that this up-keep can be reduced to a minimum with the introduction of electricity.

It is necessary for individual mines, which are not getting power from a central power plant, to have boiler installations sufficient for their peak loads. The hoist at anthracite collieries works at its maximum duty from 7 a. m. until 4 p. m. All the rest of the time its duty is very inter-

mittent. It is not possible to take these boilers out of service at night—the only thing to be done is to damp them down, which as you know, is not good for boilers, and the consumption of coal still goes on, as you can readily see from the figures in my paper. With our present slip-ring induction hoist, there is no consumption of current when the hoist is not in operation; the only losses we have are the transformer and line losses, which are about 4 per cent.

Before the use of electricity for driving mine fans, you could find steam lines in the anthracite region from one to two miles in length, covered with the best grade of insulated pipe covering. Or, if a steam line is not used, it is necessary to have an isolated boiler plant, which means more labor, up-keep, and fuel. The power lines to our electric fans are run with No. 4 wire, at 11,000 volts. In four years we have only had two interruptions, due to broken-down insulators, and no up-keep on this equipment.

H. M. Crankshaw, Hazelton, Pa.—The addition of one feature I think would strengthen this paper materially. Mr. Hobart has not mentioned the cost of the complete change; that is to say, of scrapping the steam plant and installing completely new electrical equipment. This new equipment costs money, and to justify the change, you must get enough return to make it worth while. The margin shown by Mr. Hobart is quite ample, and if he would consider the capital cost and then figure the depreciation against the electrical equipment I think it would strengthen his paper materially.

R. E. Hobart.—There was a reason for not making this comparison. The development of the new No. 11 shaft necessitated a new plant, and the question was whether it should be steam or electric. The boiler room, hoisting engines, air compressor, and fan for the old shaft were on top of the mountain; however, we hoisted only to the water-level tunnel, not to the top of the mountain. This water-level tunnel was on the same level as the top of the new shaft which was to be sunk at that point. In sinking this new shaft we tapped the old 266-ft. level and drove the shaft two levels below to develop the lower measures. The sinking of this new shaft meant new pump rooms, with new pumps, either steam or electric, and a new fan on the south side which would take the place of the fan on top of the mountain. If steam was to be used for power an entire new boiler plant was necessary.

To get all the costs in 1918 for a steam plant which would have been built in 1913, simply for the preparation of this paper, required an amount of work which I did not think necessary, and moreover, I do not see that it would be of any use. Fortunately for the accuracy of the figures given in this paper, the water was pumped and the coal was hoisted from the same level and with the same lift as when the mine was operated with

steam power. At the present time we are developing the lower levels with an electric tender hoist, which is used exclusively for this work. The main hoist is operated only for hoisting coal from the 266-ft. level. I feel that I am safe in saying that the cost of a steam plant large enough to do the work we are now doing electrically would cost more than the electric plant installed at this operation.

Eli T. Conner, Scranton, Pa.—Mr. Hobart's conclusions as to the efficiency and economy of electrification, I think can easily be proved. I have under my charge a colliery where two boiler plants of a combined rating of 3300 hp., usually overloaded, of comparatively modern type, had been in service, for 5 or 6 years, operating compressors, hoists, pumps, and a direct-current generating plant, distributing to an extreme distance of 10,000 ft. The voltage, starting at 275, was often down to 150 by the time it got to the back end of the mine. The results naturally were unsatisfactory, and it was determined to modernize the whole plant.

The conclusion reached after careful study was that complete electrification, to the extent of about 1500 kw., would serve the same purpose. The electrification has not yet been quite completed, but we have gone far enough to satisfy ourselves that we can operate the plant with about 1500 kw. input, alternating current, converted to direct current where necessary for underground transportation.

The apparent results indicate a saving of more than 50 per cent. of the fuel formerly burned, which is thereby released for the market. The estimated economies with a capital expenditure of $125,000 for new apparatus, were $50,000 per year. At that time fuel was figured at $1 a ton; the same fuel today is worth $2 a ton, or more; hence the economies by electrification will probably be close to $85,000 per year.

Briquetting of Anthracite Coal *

BY W. P. FREY,† MECH. E., LANSFORD, PA.

(New York Meeting, February, 1918)

THE briquet plant of the Lehigh Coal and Navigation Co., at Lansford, Pa., has previously been referred to.[1] It has passed the stage of experiment and now rests on a foundation practically and financially sound. The purpose of this paper is to explain how success has been attained, and to set standards for the development of hard-coal briquetting which may eliminate future failures. All the conclusions are based on actual results, avoiding speculation and theory.

Up to three years ago, the L. C. & N. Co. used coal-tar pitch as a binder in making hard-coal briquets. The plant operated with a monthly output of 300 to 600 tons and was unable to meet its own expenses. Naturally, no one was satisfied, especially as the ideals of a smokeless briquet were still unrealized. Then came the Dutch oil process, introduced in this country by the General Briquetting Co. of New York. This process uses as binder a small percentage of heavy residue of petroleum, which, being liquid, permits great economy of handling; it also did away with the most objectionable fumes of the former briquets. This oil[2] is not absolutely smokeless; heating the fresh fuel to red heat liberates some low-volatile hydrocarbons, yielding a white smoke which is not objectionable. On the other hand, this oil adds to the briquet about 7 per cent. of volatile matter, giving the product a heating capacity equal to that of the best free-burning anthracite coal.

The average silt used in the manufacture of these boulets averages 16.5 per cent. chemical ash, corresponding to 12,000 B.t.u. per pound of coal. The Hydrolene used as binder runs about 17,500 B.t.u. per pound, and approximately 7 per cent. of it enters into the mixture, hence

12,000 × 0.93	11,160 B.t.u.
17,500 × 0.07	1,125 B.t.u.
Total	12,385 B.t.u. per pound of briquets

* Originally presented at a meeting of the Pennsylvania Anthracite Section, on Nov. 24, 1917.

† Fuel Engineer, Lehigh Coal and Navigation Co.

[1] *Trans.* (1911) **42**, 367; (1915), **51**, 220.

[2] Melting point 160°. Called Hydrolene by the Sun Oil Co., Philadelphia, and the Atlantic Refining Co., Philadelphia, and Asphaltum by the Standard Oil Co.

The gain over the original coal is 385 B.t.u. or 3.2 per cent.

The briquetted anthracite thus averages 12,385 B.t.u., 12 per cent. volatile matter, and 16.5 per cent. chemical ash, and is a most valuable fuel. It is well adapted to the requirements of the kitchen range, it is an excellent fuel for the hot-air furnace and steam boiler and for other general purposes; and around our mines, it has successfully replaced bituminous coal in the operation of certain classes of steam shovels, steam rollers, and mine locomotives. It has been tested on the heavy freight engines of the Lehigh & New England Railroad, in narrow, semi-wide, and wide fireboxes, and in every test this briquetted fuel has shown steaming qualities equal to the best free-burning coal having the same percentage of ash. Of course, even free-burning anthracite cannot replace high-grade bituminous coal for locomotive fuel, but it can be mixed half-and-half with such coal, either by mixing anthracite briquets with soft coal, or by briquetting a mixture of hard and soft coals. This 50–50 mixture will burn with the same steaming qualities and efficiency of combustion as the bituminous coal. The mixture can even be compounded in the proportion of 15 bituminous coal to 85 of briquets, but this necessitates the consumption of 15 to 25 per cent. more fuel for the same boiler rating. Several instances could be cited where factory owners, unable to secure bituminous coal for their boilers, had to replace it entirely by anthracite briquets, and did so without materially increasing their fuel bill. The anthracite briquet, as a rule, does not mix well with straight anthracite coal.

It is obvious that the briquets must be made of a raw material in which the ash content is low enough to prevent clinkering; in general, below 18 per cent. This is an important point, as this requirement excludes from direct briquetting most of the large anthracite culm banks now available at the various mines. Not until lately has it been possible to develop machinery which will practically and cheaply furnish the silts required. The Lehigh Coal and Navigation Co., using a combination of cone separators and shaking tables, has been entirely successful in solving this problem. It is almost unnecessary to add that the briquet made from hard coal and Hydrolene is absolutely waterproof, and very tough and hard, resulting in minimum breakage during loading and dumping.

The remainder of the problem of successful briquetting is a question of mechanical engineering alone. The layout of Fig. 1, showing the remodeled Lansford plant, serves as an illustration. The output of such an installation is limited by the capacity of the presses, in this case being 40 tons per hr.; this therefore determines the size of the dumping arrangements, the driers, and the mixers. Much care should be exercised in the choice of a dumping device; it should be light enough to be entirely automatic and heavy enough to stand the destructive rubbing

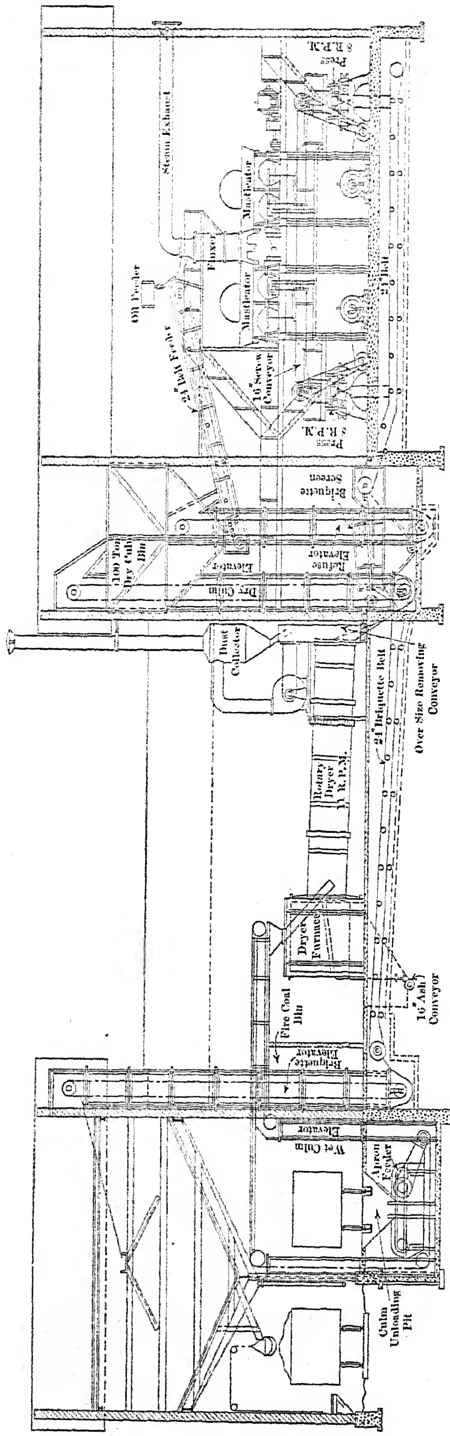


FIG. 1.—LONGITUDINAL SECTION OF PROPOSED LANSFORD COAL-BRIQUETTING PLANT. CAPACITY, 40 TO 50 TONS PER HOUR, WITH FOUR PRESSES.

action of the coal and the corrosion of acid water; it must also be frost proof, well drained, and easily accessible.

The steel hopper shown in Fig. 1 is provided with an adjustable gate. The bottom of the hopper is formed by the steel apron feeder, which dumps the coal onto a V-bucket elevator; this takes the coal to the top of the drier building and dumps it into steel chutes leading by gravity to the two driers. The apron feeder has a speed of 30 ft. (9 m.) per min. The V-buckets are each 15 by 16 in. (38.1 by 40.6 cm.) rigidly mounted on No. 1112 Link-Belt chain; their speed is 80 ft. (24.3 m.) per min.

The two driers are of the rotary single-shell type, 36 ft. (10.9 m.) long, 6 ft. 5 in. (1.96 m.) inside diameter, and slope ⅜ in. (9.53 mm.) per foot. Their speed is 11 r.p.m. This arrangement is very simple and cheap, but has the disadvantage of sending a heavy black smoke of coal particles up the stack, which can be prevented only by dust collectors or by incomplete drying. The fuel used for the drier furnace is No. 3 buckwheat, and under good conditions 70 tons of culm are dried per ton of coal burned. A screen attachment at the end of the dryers removes all oversize and foreign material. The dried coal is fed directly into two double-strand, continuous, bucket elevators with steel casing and 12 by 8 by 12-in. buckets, which deliver it to two dry-coal bins of 100 tons capacity each. Sufficient silt is always kept in cars outside of the plant to insure continuity of operation. The purpose of the dry-coal bins is to equalize the supply to mixers and presses, and eliminate fluctuations due to lost time in dumping cars or repairing machinery in the drying plant. The driers and dump require 50 h.p.

The culm now being dry, special attention must be paid to the prevention of unnecessary dust. For carriers of dry culm, only screw or belt conveyors can be used, and these must be enclosed in dust-proof casings. Belts always spill coal on the under side, and provision should be made so that this waste material may easily be removed or recovered without loss of time. Screw conveyors can be used advantageously for either wet or dry silt, and conveyors of this kind over 100 ft. (30 m.) long are in use, causing but little trouble; for greater distances belt conveyors are preferable because lighter, cheaper and faster.

From the dry-coal bins, the coal should be delivered by the shortest possible route to a mixer, where the hot oil can be thoroughly mixed with it. A preliminary mixing of oil and coal is given in a slightly inclined paddle mixer 3 ft. long, the diameter of the paddles being 20 in. and its speed 75 r.p.m. The oil is fed at a temperature of about 250° F., while the coal is around 100° F. The handling of this hot mixture of oil and coal presents some difficulties, as, on chilling, the oil becomes very sticky, and adheres readily to metal. At 250° F. the oil will flow like water; at about 70° it is hard and brittle; at about 175° its stickiness is greatest; and at 135° stickiness disappears. Two methods of handling

the mixture are thus indicated: the coal and oil mixture may either be kept at a temperature close to 200° F.; or it may be held around 150°, while the shell and metal parts are kept so cool that in contact with them the oil chills immediately to a non-sticking mass. The latter plan has been adopted in the Lansford plant, though for reasons of economy it would be better to keep the mixture hot; we expect to improve this machinery until it will be possible to handle a hot coal and oil mixture satisfactorily.

For the preliminary mixing in the paddle mixer, a light and steady flow of water keeps the trough cool. This mixing is but a mechanical stirring of oil globules and small particles of coal, and results in a very crude and imperfect surface coating of the oil with coal dust. After a while the cooling water enters the mixture, moistening the excess coal dust and the surfaces of the coal-coated oil globules, thus acting as a welcome lubricant which helps greatly to make the sticky mass flow more freely. (This amount of moisture will have to be kept around 3 per cent.) From the short paddle mixer, the coal and oil mixture is discharged into a vertical paddle mixer, or fluxer, so called because here, in addition to mechanical mixing, a moistening and heating effect is obtained, which brings the mass to the plasticity of a perfect flux, hot enough to be adhesive and moist enough to make handling easy. The flux then goes through the masticator, a Chilean mill of huge dimensions, where a thorough mixing of ingredients occurs. The masticator is the backbone of the patents covering the Dutch oil process. It could be eliminated, but the saving in royalty would generally be offset by the cost of additional oil. The speed of the masticator is 20 r.p.m.; 12.5 tons of material per hour are efficiently masticated. It is built in single-unit or in twin-unit types—local conditions will determine the choice; the single-unit type requires 100 hp., and the twin-unit type 150 hp. The masticator discharges centrally through a horizontal 12-in. screw conveyor (at 60 r.p.m.) to the presses.

The vertical feed box on top of the press contains a vertical stirrer which keeps the flux in motion, insuring equal and continuous feed (Fig. 2). The press shafts should be well dimensioned, as they often break from fatigue. The press used in the Lansford plant is known as the Belgian eggette press; it was selected after investigations covering several other types of presses. The peripheral speed of the press rolls is 80 ft. per min. The die rings are either of cut and milled steel or chilled cast iron. The output of this press is now over 10 tons per hr.; this increase from 4 tons to 10 (the original guaranteed output having been 4 tons per hour) has been a vital feature in the success of the plant.

As the briquets leave the press warm, some care has to be taken in handling them until they are sufficiently cooled to become hard. At the Lansford plant the boulets drop onto a 24-in. belt conveyor and are taken

to a rotary screen, where all waste breakage is removed and sent back to the presses. The boulets from the rotary screen are delivered by a single 24-in. belt to a double-strand continuous bucket elevator, having 18 by 8 by 12-in. buckets, which discharges into a 300-ton pocket with a perforated bottom. There sufficient time is allowed to cool the boulets

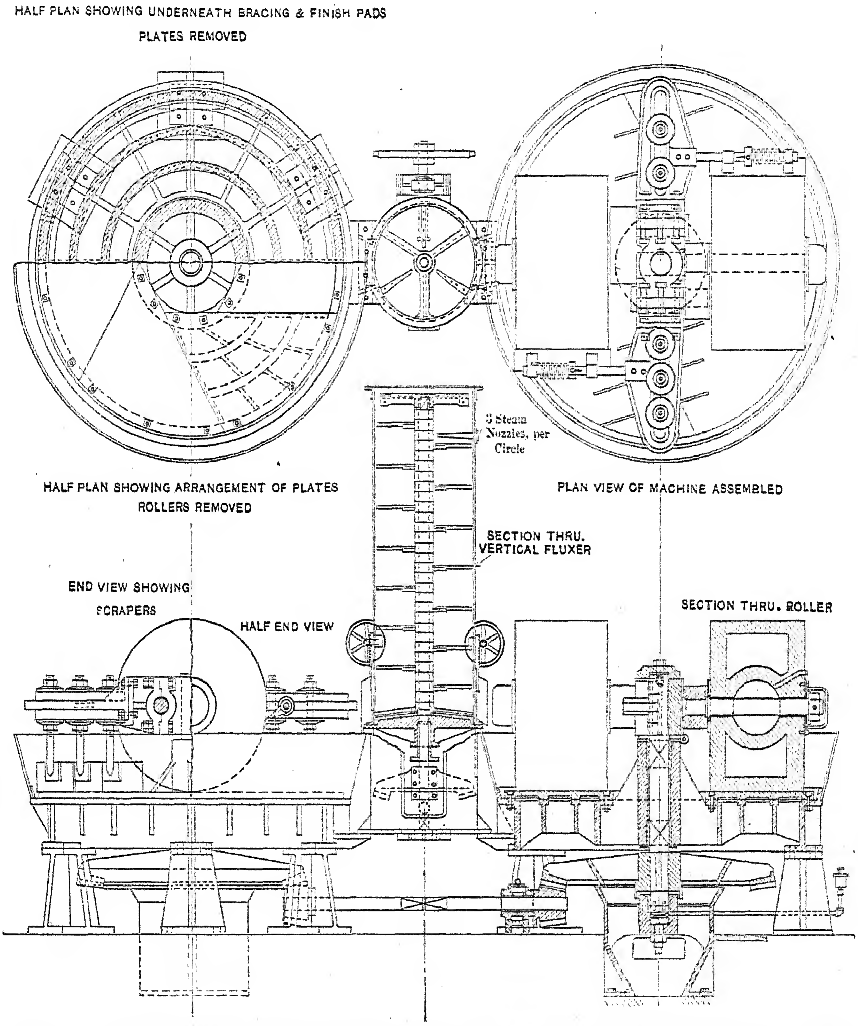


Fig. 2.—Arrangement of one set of edge runners and one vertical fluxer.

before they are loaded into cars. During the hot season, the cooling is accelerated by water sprays. Breakage through storing and loading amounts to less than 2 per cent.

The handling of the oil requires special steam-heated installations. As the oil is a manufactured product, provisions should be made for ample

storage capacity, amounting to at least two weeks' supply. Any insulated tank will answer the requirements; it should be provided with a good non-leaking radiator having a temperature control. Oil should not be kept too hot; if it is, its melting point will rise because of the evaporation of volatiles. At Lansford a 70,000-gal. tank is being used as the main storage, maintaining the oil at 180° F., and a 12,000-gal. tank for immediate use, with the oil at 275° F. A steam-heated, electrically driven, Kinney rotating pump provides circulation in the oil system, and has been in continuous and satisfactory service for over two years.

Generally speaking, all oil lines have to be steam heated. This is done by laying 1-in. steam lines beside the oil lines (not smaller than 2 in.) and wrapping the two together with good insulating material. Only quick-closing gate valves should be used. To insure a uniform flow of oil, an overflow feeder tank is provided at the spot where the mixing of coal and oil is desired; a steam-heated gate valve affords the necessary adjustment. Much attention is paid to the proper operation of the oil equipment, as the cost of oil is the largest single item in the cost of manufacturing boulets.

Cost of Manufacture

Applying present market prices and wage scales, the following table gives the cost per ton of manufacturing hard-coal briquets:

Oil binder	$1.25
Clean silt delivered at plant	1.00
Superintendence and labor	0.40
Power, light, heat and water	0.15
Supplies	0.05
Maintenance	0.05
Interest on investment	0.10
Depreciation	0.20
Insurance, compensation and taxes	0.05
Royalty	0.10
Total cost per ton	$3.35

These figures, though conservative, will give ample protection to a prospective manufacturer. A plant, such as shown, represents an investment of $250,000, exclusive of ground and tracks, at the present market prices. The boulets find a ready market at $4 a ton, leaving a comfortable margin of profit. The popularity of boulets as a domestic fuel has grown in every district where they have been introduced, and there would be no difficulty in marketing a largely increased output.

DISCUSSION

Burke Baker, Philadelphia, Pa. (written discussion*).—The small briquetting plant of the American Briquet Co., at 25th Street and

* Received Jan. 23, 1918.

Washington Ave., Philadelphia, was built primarily as a demonstration plant. Its output per hour is 4 tons of 2-oz. briquets, which have been retailed in the vicinity during the year the plant has been in operation. They have proved very acceptable for use in ranges, heaters and grates in homes, and in steam heating plants in apartment houses and hotels. They have not been sold for power purposes, although satisfactory tests have been made in this field. Anthracite silt is used and is shipped direct from breaker or washery, the only preparation it receives being the removal of excess moisture by means of a Ruggles-Coles rotary dryer. Care is taken, however, to purchase silt containing less than 18 per cent. ash.

The method is covered by U. S. Patent No. 941454, issued to Chas. E. Hite, and is known as the "emulsion process." The binder, which is the basis of the patent, is composed of 0.5 per cent. cornstarch or wheat flour; 1 per cent. asphaltum or hydrolene, and 6.5 per cent. water, on the weight of coal dust. It is prepared in a tank equipped with paddle agitators and heated by steam jets. The starch and water are first made into a paste by being brought to the boiling point with live steam; the melted asphaltum is then introduced and thoroughly beaten into the paste by the agitators. This rapid stirring breaks the hot asphaltum into minute particles which are distributed through the paste, producing a smooth chemical emulsion. This emulsion, when dried, is not soluble in water.

The binder is mixed with the dry coal dust in a horizontal paddle mixer, 8 per cent. binder to the weight of coal being used. The resultant plastic mass is then discharged into the press, which is of the simple roll type. Since the binder is a liquid and is not sticky or gummy until partly dried, it is readily mixed with the coal dust, and a fairly uniform mixture is attained with ease.

From the press, the briquets are conveyed to a drying oven. Here they are distributed 6 in. deep over a broad screen-conveyor which passes through a "tunnel" constructed of hollow tile. Through this tunnel and up through the layer of briquets, a current of air is drawn by an exhaust fan at one end of the dryer, the air having been heated to approximately 225° F. by a furnace at the other end. The speed of the screen-conveyor is such that the briquets are in the dryer one hour before they are discharged into an elevator which carries them to the loading chutes. This dryer is similar in design to those used in the textile industry and in the drying of ores.

The briquets thus made constitute a thoroughly satisfactory fuel for use wherever the prepared sizes of anthracite are consumed. They are water-proof and weather-proof; they withstand rain, freezing and thawing, the hot sun, or the heat of a boiler room, or all in succession. They are hard and tough enough to withstand rough handling, and can be piled in large quantities without softening or sticking. They hold

their shape in the fire until completely consumed, and do not soften or fuse at any time. They are practically free from odor or smoke, and are entirely free from fumes or gases that hurt the eyes or skin, or injure flues and grates.

Although the asphaltum process as practised by Mr. Frey at Lansford, and described by him in this paper, has been very satisfactory, and is certainly a great step forward in the industry in this country, still, the emulsion process has certain distinct advantages, which may be outlined as follows:

The total cost of binder, of drying, and of interest and depreciation on additional equipment in the emulsion process, is 65 c. per ton of briquets. The cost of the asphaltum binder, estimating 7 per cent. to the weight of briquets and $17.50 as the price of hydrolene, is $1.22 per ton. Thus there is an actual saving in the cost of manufacture of 57 c. per ton.

The emulsion binder, with its 1.5 per cent. of outside raw materials, instead of 7 per cent., greatly reduces the dependence upon outside sources of supply, thus avoiding many shutdowns due to delayed deliveries of asphaltum.

An asphaltum of a high melting-point and low penetration is required in the oil process. This is produced by only one or two of the large refineries. In the emulsion process, any grade of asphalt from crude petroleum to that of the highest melting-point can be used, thus permitting the purchase of the lowest-priced product from any refinery. The other raw material—½ per cent. of cornstarch or wheat flour—can be bought in the open market and from many sources.

By using only 1 per cent. instead of 7 per cent. of oil, the objectionable features of smoke, odor, and soot are correspondingly reduced. The amount of smoke or odor produced by the 1 per cent. of asphaltum in its emulsified form is almost negligible; and there is no soot whatever.

The emulsion-binder briquets do not soften under heat. They can therefore be shipped in hot weather and to any latitude without danger of sticking in the cars; they can be stored in large quantities in summer without softening, and they do not soften and fuse in the fire, even under forced draught.

The emulsion process is not so simple as the asphaltum process, since the preparation of the binder and the drying of the briquets, although simple enough in themselves, require additional equipment. But this is compensated by the greater ease of mixing the binder with the dust. The "masticator" is unnecessary, and the need of keeping the flux at the proper temperature is obviated. On the other hand, the lower cost of production and the superior character of the product would seem to mark this as another forward step in the industry.

The American Briquet Co., after having operated its small plant in

Philadelphia for a year, and having thoroughly proved the quality of the product and the practicability of manufacture on this small but commercial scale, is now making contracts for the erection of a plant of 50 tons per hour at Lykens, Pa., where arrangements have been made with the Susquehanna Collieries Co. for a supply of silt produced by the colliery at that point.

Arthur H. Storrs, Scranton, Pa.—I would like to ask whether this same process is applicable to bituminous coal?

Felix A. Vogel, New York, N. Y.—This Dutch process is applicable to bituminous or any other kind of coal. The Berwind Fuel Co. has had a plant in operation, in Superior, Wis., for about 2 years, using the Dutch process, and it has made a very satisfactory briquette, using Pocahontas coal.

There is just one item in Mr. Frey's paper I would like to discuss; that is, the matter of cost. Mr. Frey figures a total cost of $3.35, based on the use of 7 per cent. of oil. Of course, the price of oil has advanced seriously within the last year or two, and any possible reduction in the percentage of oil required in the manufacture of briquettes is very important. I believe that Mr. Frey will agree that very good briquettes can be made with considerably less than 7 per cent. of oil; in fact, actual experience has shown that it can be done with less than 5 per cent. The only possible effects of a low percentage of oil, particularly in anthracite briquettes, are that the briquette might not burn so freely, and that it might not be quite so hard. Briquettes made by the Lehigh Coal & Navigation Co., using 7 per cent. of binder, are extremely tough. Those briquettes have been handled in one of the local yards in Brooklyn, chuting them from railroad cars into boats and digging them out by grab buckets, and the losses average less than 2 per cent. This compares very favorably with domestic anthracite coal, with which the losses from breakage amount to between 7 and 10 per cent.

J. B. McGraw, New York, N. Y.—Mr. Frey has referred to the possible necessity, in warm weather, of using water sprays for cooling the briquettes. He has developed a very satisfactory system on that basis, but in some parts of the country, the cost of the water for that purpose might be extravagant.

Five or six years ago when I was in charge of a briquetting plant we were confronted with a similar cooling problem. That plant was using melted pitch and carrying the coal at a high temperature, the briquettes being pressed at 160° to 175° F. In our case water was costly, and we devised an air-cooling system which consisted of two vertical circular tanks that would hold about 22 tons each. These tanks had baffles on the inside so arranged that the briquettes were separated into small

bodies instead of being in one large bulk. A pipe, capped at the top, passed up through each tank, from which a large volume of air was distributed throughout the mass of briquettes, cooling them in an efficient and satisfactory manner. The air was supplied by a steel-plate fan which required about 25 horse-power.

One advantage of the Dutch process, which is of considerable importance as compared with other methods with which I am familiar, is that it is possible to treat coal, by this masticator, that has not been thoroughly dried, as is found advantageous and necessary in other methods. The presence of 2 or 3 per cent. of uncombined moisture in the coal when the binder is added has no bad effects. With ordinary methods of mixing, the presence of water in the coal, if the temperature of the oil is not sufficiently high, tends to chill the oil and cause it to form globules, making it difficult to obtain a thorough mixture. Where the mass is subjected to mastication, the presence of moisture has a tendency to saponify the oil, and has the advantage of reducing the cost of drying. In any process requiring the coal to be dried absolutely, the maintaining of proper and uniform temperatures is quite difficult; hence, if moisture can be present without disadvantage, it is a big saving.

J. B. McGraw (written discussion*).—In Mr. Burke Baker's description of the process of the American Briquet Co., he speaks only of the attractive features, but every process which uses a compound or emulsified binder has certain undesirable features which must be considered.

In making an emulsion, the success of which depends upon the introduction of the various ingredients at certain fixed temperatures and the complete intermixing of a soluble solution with an oil which has absolutely no affinity for it, considerable difficulty is found in keeping the various factors in strict accordance with the formula. To serve its purpose properly or, in other words, to be right for easy mixing with the coal, it should be of a certain predetermined density. Among the controlling factors of this are the proportion of moisture contained and the temperature of the oil when introduced. If the latter is higher than intended, a greater proportion of moisture will be evaporated than is proper, and if the oil is not sufficiently hot the process of emulsification is retarded.

These various factors can be controlled with more or less certainty when working in a laboratory or in a small experimental way, but when it is attempted on a large commercial scale, certain obstacles not otherwise apparent are likely to be encountered.

Another feature which does not appeal to the experienced briquetting engineer is the necessity of drying or baking the briquettes before they can be shipped. It has been found by past experience that the prob-

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* Received April 4, 1918.

lem of maintaining the necessary uniform temperature throughout an oven of the size required is extremely difficult. Unlike textiles or loosely laid pulverulent materials, such as iron ore and the like, briquettes, because of their greater density, must be exposed to the drying temperature a greater length of time. If they could be dried in batches it would be a simpler proposition, but as the oven must be of a continuous operating type, in keeping with the rest of the plant, the difficulties are increased.

It is true that a certain degree of success has been attained in operations on a small scale, but it is notable that in the entire history of briquetting in this country no process which requires the drying of briquettes has ever been developed on a large scale.

In the case of briquettes made with a starch binder, it is necessary not only to drive off the moisture but actually to bake them in order to convert the starch into coke before they become weather proof. This requirement further complicates the problem.

A briquette from which 6 per cent. or more of moisture has been dried out cannot have the strength or density to resist the shocks of ordinary handling which it should have. If properly mixed, the moisture will have been distributed throughout its mass in infinitesimal globules, and after this is evaporated the structure will be porous and very much weakened.

To be a commercial success, a briquetting process should be as simple as possible and the product should be strong and tough enough to withstand the same treatment in loading and unloading as ordinary anthracite coal, with little or no breakage.

The failure of many briquetting enterprises which started out under apparently favorable conditions can be laid to the presence of one or more complicated features which failed to work out in practice as intended.

Heating of Coal in Piles

BY C. M. YOUNG,* E. M., URBANA, ILL.

(New York Meeting, February, 1918)

Bituminous coal piled in heaps or bins frequently undergoes a process of spontaneous heating as the result of the absorption of oxygen. It seems probable that the first absorption of oxygen by coal which has not previously been exposed to the air may occur as a condensation or a combination of oxygen in some form which does not result in the production of carbon dioxide, but slow combustion soon begins. The absorption of oxygen is accompanied by an increase of temperature, and this by an increased rapidity of absorption; hence the dangerous condition proceeds from bad to worse, until the kindling point is reached, unless the process is interrupted.

A dangerous rise of temperature can be prevented by excluding oxygen, by increasing the bulk of coal in proportion to its surface exposed, or by circulating enough air to dissipate the heat produced. The storage of coal, in practice, varies from almost complete exclusion of oxygen, by storing under water, to such freedom of access as exists when the coal is stored in open piles.

Oxygen available for absorption by coal is supplied by the air in the interstices between lumps and by additional air which may enter the pile through circulation. The size of the coal largely affects both of these supplies; for if the fragments are small the spaces between them constitute a small percentage of the total volume, and little oxygen will be available unless the circulation of air brings in a fresh supply, while with large fragments the percentage is relatively large; circulation also is much easier through a pile of coarse lumps. In the case of lump coal, although a large amount of air may be present, the exposed surface is comparatively small and there is little opportunity for the absorption of oxygen to be so rapid as to cause dangerous heating. Attempts have been made to prevent heating by allowing a sufficient circulation of air to carry off the heat generated; obviously this method cannot be applied to fine sizes nor mixed sizes.

When storing coal at the University of Illinois, an attempt has been made to use so much fine coal and to pack it so thoroughly as to prevent circulation of air, while also reducing the original air in the pile so as to prevent heating. This method has been fairly successful, but in some

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cases the piles have heated. An investigation made when a pile was opened for the removal of portions which had begun to heat indicated that heating had occurred only in those parts of the pile which contained comparatively small proportions of fine coal.

To confirm the impression given by the appearance of the pile, samples of coal were taken from the spots where heating was evident, and from neighboring regions in which there was no evidence of heating. These samples were then sized on screens ranging from 2-in. to ⅛-in. round hole, giving the following results:

Size, In.	Heated Region		Unheated Region	
	Per Cent.	Cum. Per Cent.	Per Cent.	Cum. Per Cent.
Over 2	0.0	......	0.0	......
1-2	32.6	32 6	6.3	6 3
½-1	36 4	69 0	22.9	29.2
¼-½	12 2	81.2	24 8	54.0
⅛-¼	7 4	88 6	18 5	72 5
Below ⅛	11 4	100.0	27 5	100 0
	100.0	.....	100.0	....

It appears from this examination that the portions of the pile in which fine sizes were present in largest proportion did not contain sufficient oxygen to heat the coal to any noticeable extent. The close packing had also so obstructed circulation that little fresh oxygen could have been brought in even if the temperature had been raised to such an extent as to favor circulation of air. This indicates that one comparatively safe way to store coal is to use enough of the fine sizes to occupy the space as completely as possible, and to pack the coal tightly in order that the air space may be reduced and the circulation of air restricted. Apparently the most dangerous condition exists when the coal is of such sizes as to present a large aggregate surface for absorption, and at the same time leave sufficient air space to provide the oxygen required for heating; this condition is found in a loosely packed pile of mixed sizes.

Review of the Coal Situation of the World*

BY GEORGE S. RICE, WASHINGTON, D. C.

(New York Meeting, February, 1918)

WITH so tremendous a subject, an attempted review of the coal situation of the world in a short talk must necessarily be of a sketchy character. It is hardly necessary to tell a body of engineers that had it not been for nature's gift of coal the material side of modern civilization would never have reached its present status. On the other side, it is regrettable that it was a byproduct of coal, T. N. T., which made possible Germany's initial success in this war, because that country had an enormous development of manufacturing plants that could be immediately utilized to make this destructive agent.

One sometimes hears the casual remark that when the coal of the world is exhausted we shall use electricity; but, of course, electricity is ordinarily only a means of transforming and transmitting energy derived from fuel or water power, and chiefly from coal. It is true, we have much undeveloped water power, but it is more or less remote from the centers of industry; and when all shall have been developed it will not begin to supply the power requirements of the world. It is, however, reasonable to expect that before the world's supply of coal shall be exhausted, methods will have been discovered of harnessing other forces of nature, such as the tides, or the energy emanating from the sun.

Petroleum and natural gas naturally come to mind, but the days of both, as fuel, appear to be numbered, although the products of petroleum, if economically used, doubtless will be available for internal-combustion engines, automobiles, trucks, and boats for a long time, provided the reckless use of crude petroleum as an ordinary fuel is stopped. The products of petroleum are too valuable to mankind for such waste to be permitted. The civilization of the world, therefore, appears to rest, and, so far as can be seen, will indefinitely continue to rest, upon coal.

Coal Resources of the World

According to the compilation made by the geologists of the principal countries for the 12th International Geologic Congress, held in Canada

* Notes for an illustrated talk before the Washington Society of Engineers, Nov. 6, 1917

in 1912, the gross resources of coal in the world amount to over 7,000,000 millions of tons, of which 500,000 million tons is anthracite and semi-anthracite, 4,000,000 million tons is bituminous coal, and 3,000,000 million tons is sub-bituminous and lignitic coal. But these estimates include all coal down to 1 ft. (0.3 m.) in thickness and 4000 ft. (1200 m.) in depth; such extremes are not within present commercial possibilities and probably will not be for several generations at least. Resources figured on the basis of so-called "actual reserves," which means coal beds of which there is definite knowledge as to thickness and extent, give a total much smaller than the 7,000,000 million tons, or about 10 per cent. of the total, including "actual," "probable," and "possible."[1]

The United States estimates are 4,000,000 million tons (metric) of "actual" and "probable," about one-half of which is lignitic coal. Canada is credited with the next largest amount of reserves, 1,234,000 million tons, but four-fifths of this is lignitic coal. China is estimated to have nearly 1,000,000 million tons of coal; Germany is credited with 423,000 million tons; and Great Britain with 190,000 million tons. No other European country has nearly so much as the last two countries named. The coals of Great Britain have a higher average quality than the reserves of any other nation. The reserves of Russia are 60,100 million tons, Austria 54,000 million tons, and Belgium 11,000 million tons.

Annual Coal Production

The annual coal production of the world for 1913, the last year for which the returns are complete, according to the United States Geological Survey, was 1,478,000,000 short tons. Of this the United States contributed 570,000,000 tons, or almost 40 per cent. In 1913, Great Britain produced 322,000,000 short tons, or 287,000,000 long tons, the unit of measurement of that country, as it is for anthracite in this country. In 1914, the war affected the production for the last half of the year, cutting off exports to the Baltic ports, and the output of Great Britain fell to 260,000,000 long tons. In 1915, it fell still further, to 253,000,000 long tons, the output having been decreased through miners going to the front and by further curtailment of exports, especially to South America and Mediterranean ports. In 1916, the output is estimated to have slightly increased, being 256,000,000 tons; and, while the exports to distant countries have been largely curtailed by a shortage of shipping resulting from the losses caused by submarines, the home needs increased.

[1] Figures for the coal resources and production of the United States are obtained chiefly from reports of the U. S. Geological Survey; those relating to resources of other countries are from reports of the Twelfth International Geologic Congress; those relating to exports and imports are from the official statistics of the respective countries.

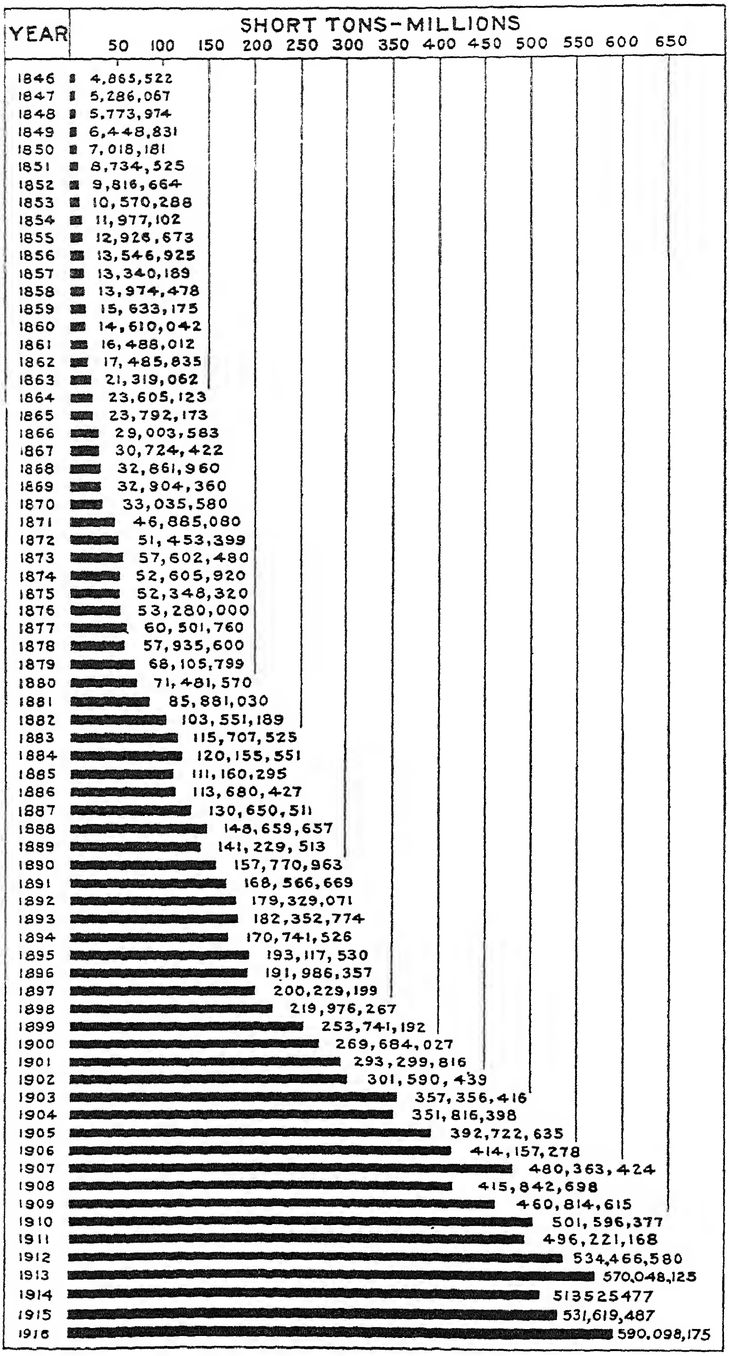

FIG. 1.—TOTAL PRODUCTION OF COAL IN THE UNITED STATES.

Germany was for many years a poor third in coal production, but in recent years its rate of increase has been almost as rapid as that of the United States, and had peace continued it would probably have passed Great Britain in production in 1915 or 1916. Its output in 1913 was 306,000,000 short tons, or 278,000,000 metric tons (2204 lb.). Of this, one-third was lignite, but this is briquetted extensively and in such excellent manner that in this form it competes with bituminous coal. In 1914, Germany's exports to Russia, France, and overseas having been cut off, the output fell off 13 per cent., the total production being 246,-000,000 metric tons. Germany's exports in 1912 were 31,000,000 metric tons, and in 1914, with a curtailment of 5 months of the war, they were, according to *Mineral Industry,* 13,000,000 tons. In 1915, the export business had fallen to 6,500,000 tons, this decline being due in part to the restrictions on the coal exported to Holland, the tonnage to that country falling from nearly 5,000,000 tons to less than 1,000,000 tons. Whether this was intended to curtail manufacturing in Holland, or because there was an insufficient supply of coal in Germany due to a shortage of miners, is a question we can not now answer.

Austria-Hungary is fourth in the rank of production, in 1913 having an output of 60,000,000 short tons (54,000,000 metric tons), over half of which was lignite. Great Britain, the United States and Germany are coal-exporting nations, but Austria-Hungary imported about 6,000,000 tons more than it exported, chiefly from Germany.

France ranked fifth in production before the war, its output in 1913 being 45,000,000 short tons (41,000,000 metric tons). Then in 1914, came the fearful check caused by the invasion of France and the loss of two-thirds of the Nord and Pas-de-Calais coal districts, which had produced about 30,000,000 tons of coal per annum; thus there was an immediate loss of production of perhaps 20,000,000 tons from the mines which passed into the hands of the Germans or were wrecked. So many miners, also, were called to arms that the production elsewhere was curtailed, and although no official figures have been issued, it is probable that the output fell to a rate of about 15,000,000 tons annually, imports from Great Britain taking care of the deficit, although it has been freely admitted that coal has been very scarce in France. The output in 1916, according to *Coal Age,* was 22,000,000 tons, and it is understood that this output has been increasing. Even before the war, France was an extensive importer of coal, importing about 20,000,000 tons, chiefly from Great Britain, some from Belgium and Germany, and exporting only about 2,000,000 tons. Consumption was thus approximately 60,000,000 tons. Great Britain sent to France in the early part of the war about 2,000,000 tons of coal monthly, the rate decreasing to about 1,500,000 tons.

The invasion of France not only caused a loss of coal production,

but in the Nord and the Pas-de-Calais basin were the chief coke byproduct plants of France.

The coal beds of northern France lie in a deep, long, narrow synclinal fold which extends easterly through Belgium to Germany. The upturned edges of the Carboniferous rocks are deeply covered by water-bearing chalks and marls. The surface is a gently rolling plain. The battle line crosses the coal field from the north to the south, originally through Loos to Arras, the latter, although south of the coal basin, was formerly the headquarters of the mining district. This battle line was forced eastward by the British thrust last spring over Vimy Ridge, which marks the southern boundary of the basin, and it now partly surrounds Lens, which was the largest French byproduct coke center. It is evident that the Germans have strained every nerve to retain as much of the field as possible.

Russia produced 35,500,000 short tons (32,000,000 metric tons) in 1913. It imported a considerable amount of coal from Germany; total imports for 1914, including the 5 months of war, were over 3,000,000 tons, but in 1915 this dropped to 47,000 tons. The Dombrowa basin in Poland is an extension of the large Upper Silesian coal basin of Germany, and produced annually about 7,000,000 tons of bituminous coal and brown coal. When the Germans advanced through Poland this basin fell into their hands. Owing to the isolation of Russia, it is evident that there must be a considerable shortage of coal, which could not be made up by development in its other basins.

Belgium, in 1913, produced nearly 25,000,000 short tons (23,000,000 metric tons) of coal; the field is in the same geologic basin as that from which France produced most of its coal. • Belgium exported coal to adjoining countries, but imported 4,000,000 tons in excess of its exports. The manufacture of coke and its byproducts was intensively carried on, and this little country was one of the most prosperous in the world considering its size and population. When overrun by the German army, the mines, of course, were seized and have since been operated under German direction. The Belgians were naturally reluctant to operate the mines for more than their own needs, and the output has been far below the normal figure, in spite of the attempts of the Germans to force more intensive work. In 1915, the output included 14,200,000 tons of coal, 484,000 tons of coke, and 1,200,000 tons of briquets, while for the first half of 1916, according to statistics quoted by A. F. Shurick, Belgium produced 8,478,000 tons of coal, 409,000 tons of coke, and 1,000-000 tons of briquets. However, a Belgian, in an unsigned letter to *Coal Age*, says that these figures issued by the Germans are not correct. It is claimed that a considerable amount of coal was shipped from Belgium to Holland in 1915, amounting to 700,000 tons.

The Germans, according to their statements, have continued the

development begun long ago by the Belgians in the new coal field in the province of Hainault in Central Belgium, but this will not be available to produce much coal for some years as the coal beds are thin, deep and difficult to mine.

I will not dwell on the production of the other countries except to point out the situation in a few of the European nations, as they are so materially affected by the war. In 1912, Spain produced a little over 4,000,000 tons and imported about 4,000,000 tons from Great Britain. It is understood that there has been an increased development in Spain, as it has been so much cut off from imports, but its coal resources are not such as to permit of great development.

Holland produced 1,725,000 tons in 1912, and imported heavily from the adjoining nations, chiefly from the Rhine provinces of Germany. Norway, Sweden, and Denmark have practically no coal resources. Formerly Norway relied on coal from Great Britain; Sweden on coal from Great Britain and Germany, and Denmark from Great Britain and some from Germany. Italy has produced annually only about 600,000 tons of graphitic anthracite and lignite, and has to depend on Great Britain for the bulk of its fuel, receiving from Great Britain about 10,000,000 tons in 1913. It is known that at the present time there is serious scarcity of coal in Italy, but it would not be discreet to give any figures. Imports by water have been much curtailed, and coal must largely pass by rail through France.

The coal production of Asia was about 52,000,000 tons, coming principally from Japan, China and India. Japan's and India's resources are more limited, and the coal from Japan is of poor quality. Chinese and Manchurian resources are capable of great development, and their future production will probably be a factor in the Pacific Ocean markets. Australasia's resources are considerable, and its production about 15,000,000 tons per annum. Most of this comes from New South Wales, the coals from which are of excellent quality and have already entered into the Pacific markets.

The resources of Africa are apparently somewhat limited. Collectively, its production has been from 7,000,000 to 8,000,000 tons in recent years, practically all from the extreme south. Little is known of the coal resources of the interior, but it is not probable that Africa will have more than enough for its own needs. At the present time, it imports coal heavily from Great Britain.

Canada has very extensive resources in its western provinces, especially in the Rocky Mountain region, and limited resources in Nova Scotia. While there is coal of high grade in British Columbia and Alberta, a great deal of the bituminous coal is found under difficult mining conditions, and is inaccessible to existing railroads. Canada imports more coal from the United States than it exports to the United

States from Nova Scotia and British Columbia, and this will probably continue to be the case, as Canada contains a long stretch of country, over 2000 miles, between Nova Scotia and Alberta, destitute of coal.

Mexico has some coal resources, but they are very limited in comparison with the ultimate needs of the country. The output for 1912, before the revolutions began, was only 891,000 tons.

As to the South American countries, Great Britain and the United States are much concerned, because the coal resources of South America are extremely limited, and they are inaccessible and not well developed. Chili produces about 1,300,000 tons of coal annually, and Peru about 300,000 tons. In 1913, the South American countries, including Cuba and the West Indies, imported about 5,000,000 tons of coal, chiefly bituminous from the United States, 7,000,000 tons of coal and 600,000 tons of coke from Great Britain, and 228,000 tons of coal from Germany.

Exports and Imports of Coal

As already indicated, the coal resources of the world are very unevenly distributed, the United States having more than its share, while coal production is still more unevenly distributed, depending upon the geographic position of the coal field with respect to the markets, the quality of the coal, and its accessibility.

These reasons explain why Great Britain has developed its more limited resources to the greatest extent. Some of its finest coals, like the Welsh steam coal, which is the standard of the world, lie within a few miles of its seaports. This great advantage over Germany and the United States has been a factor in its becoming the great coal exporting country of the world; its total exports in 1913 were nearly 77,000,000 tons. The German empire was the second largest exporter in 1913, with 44,000,000 tons; the United States was a poor third with 18,000,000 tons, of which 13,000,000 tons went to Canada. There is every reason to expect that the United States must become a larger factor in the export business of the future, despite the fact that its nearest high-grade coals require hauls of several hundred miles. While Germany has a similar disadvantage, the German government, owning the railroads, has given special help to its export business. Other than the handicap of distance from seaports, the chief reasons why the United States has not been a larger factor in the past have been: (1) the absence of shipping facilities; (2) the lack of proper dockage and distributing facilities in the chief foreign importing countries, comparable with the British and German facilities; (3) a lack of care in preparing the coal for shipment, particularly in the matter of sizing.

In the first year of the war, the output of the United States declined from 570,000,000 tons in 1913 to 513,000,000 tons in 1914; but in 1915

there was some recovery, the output being 532,000,000 tons. In the winter, the shortage of coal became acute and the increased demand stimulated the output of 1916 to 590,000,000 tons. At the beginning of 1917, the output promised to be far larger than ever before, but shortage of railroad cars and labor troubles caused a falling off in output of the later months.

It was expected soon after the war began, that the United States would materially increase its export business to South America, due to the completion of the Panama Canal and to the shutting off of Germany from all exports; and that to some extent, owing to England's shortage of men, the United States would export more extensively to Mediterranean ports and to France. This condition prevailed, the rise in exports in 1915 having been very noticeable. Exports to Italy were 3,283,000 tons, to France 251,000 tons, to Greece 82,000 tons, to Spain and Portugal 272,000 tons, and to Sweden 263,000 tons. However, Germany's submarine campaign and the increased scarcity of shipping has gradually reduced exports to Europe.

Bituminous Coal Consumption

It is interesting to review briefly the chief items of coal consumption, and we are indebted to the Geological Survey for compiling statistics covering this feature.

The greatest consumption of bituminous and lignite coal is for industrial steam purposes, amounting, in 1915, to 144,000,000 tons, or 33 per cent. of production in the United States. The railroads come next as consumers; in the same year they burned 122,000,000[2] tons, or 28 per cent. of production. The third great use of coal is for domestic purposes and small steam trade, amounting to 71,000,000 tons,[3] or 16 per cent. The three foregoing requirements, therefore, consume 77 per cent. of the production. Coal for coke making, used principally for steel manufacture, took 13.6 per cent. of the production. Exports took 4 per cent.;[4] 2 per cent. was used at the mines for steam and power purposes; steamship bunker coal amounted to 2 per cent., and 1 per cent. was consumed in the manufacture of coal gas.

Operating Conditions

Regarding the difficulties of mining, the United States is as favorably situated for its coal development as it is highly favored in quantity.

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[2] Anthracite used by railroads, 6,200,000 tons.

[3] Mr. Lesher estimates 60,000,000 tons of anthracite used for heating purposes.

[4] Exports 18,776,640 tons (net) bituminous coal and 3,965,255 tons (net) anthracite (exported chiefly to Canada).

The coal beds of Europe, particularly in Belgium, France and Germany, and to a less extent in England, are badly broken by faults; the coal is more or less crushed, the beds are thin in Belgium and Northern France and in the Rhine coal districts, the mines are deep and hot, but the very difficulties thus presented have caused the art of mining to become further advanced than in our country.

In the United States the coal is shallow, and except that in mountainous districts, is easily mined; machines may be used, and as the coal in the ground has been cheaply purchased, with no necessity for economical extraction, mining methods have generally been wasteful. Most operators will admit this in private, but they can truthfully say

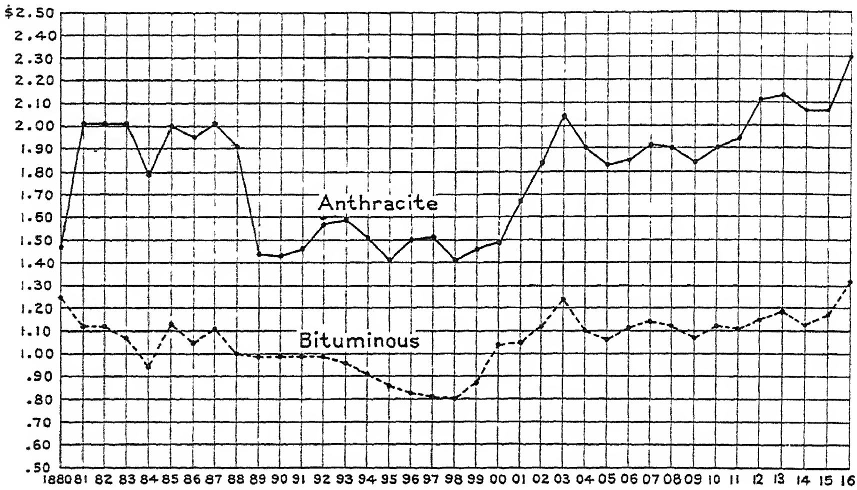

FIG. 2.—AVERAGE PRICE PER SHORT TON OF COAL, AT THE MINE, IN THE UNITED STATES.

that the competitive conditions arising from over-development of new mines have been so extreme and prices so low, until a year ago, that the more improved European methods of mining could not be generally used here, because to mine intensively and get out all of the coal, it must be admitted, is not the cheapest manner of production.

To get cheaper coal, only the best coal is taken, convenient to the shaft or drift mouth, and the inferior, thin, and irregular coal is left. In many districts they do not extract the pillars, because to take out the pillars completely means added expense. The excavations must be more or less packed with rock, or by sand filling, as is now done extensively in Germany, to some extent in France and Belgium, and also to a limited extent in our anthracite district, which first developed this valuable system.

In general, the miners' unions in this country (I speak as one who believes in responsible unions properly administered) have tended to

unify wages on the basis of the most easily extracted coal, and inferior conditions are so severely penalized that the operators cannot introduce new or improved methods. We all hope for a better day when the membership of the unions will appreciate, as citizens and members of a skilled craft, that they too have their duty to perform in trying to obtain the maximum amount of coal by using the most improved methods, and will accept difficult work, just as the operators should forego some of the profits, when there are profits, while aiming at higher recoveries for the benefit of future generations.

I have used the word "waste," and yet it should be understood that mining waste is not wilful or even careless wastage, as is commonly assumed by those unacquainted with mining. Each can take home to himself whether or not he would be willing to forego the use of his dollar of profit today, in order to leave a ton or more of coal in the ground in such form that it may be secured by some other persons in the future, perhaps not even his own descendants. This is where control by the Government has in the past played a part in the case of European countries, and perhaps it would be advisable in this country. While the coal might cost 10 to 25 per cent. more to produce, all operators would be on the same basis, and business would still be done on increased prices, just as prior to the war it was done most profitably in Germany and France, although the cost of the coal to the consumer was double or treble its cost in this country. It would be idle to try to apply these percentages to the present cost of producing coal, because conditions are now so abnormal, the increased cost of labor and material having entered so largely into the high cost of production at this time. For years, the average for run-of-mine bituminous coal has been from $1 to $1.15 per ton at the mine; but I believe that the day of extremely cheap coal in this country is past, and that when the war is over we shall see the need of compelling more nearly complete recovery of coal at the mines. Also a better utilization; the average consumer is quite as wasteful as the miner, no doubt unknowingly and unintentionally, and not so conspicuously, but noticeably so, nevertheless, in the opinion of fuel engineers.

As to coal production in the United States at this time, in which so many are vitally concerned, I have no sources of confidential information, and merely speak as an engineer citizen. Anthracite, of which this country has more of high quality than any other country, is difficult to recover because of folded beds and faulted conditions, much like those of the European coals. Therefore it is expensive to mine; and its hardness and interbedding with slates makes it expensive to prepare. One item of mining cost alone indicates that fact, namely, that for every ton of anthracite coal hoisted out of the mine, from 5 to 10 or more tons of water must be raised. The mines are gaseous, which means heavy ventilating expense. The coal is hard and has to be crushed by rolls,

and in the crushing a great deal of it is de-graded to dust or sludge, the finest of which is practically waste, while the coarser sludge has to be sold at low prices. Hence the ordinary domestic size must sell at nearly double the run-of-mine cost to compensate for loss of dust and the low prices of the small sizes. While anthracite coal is so important in the eastern portion of the United States, it must be considered a luxury which only the United States possesses in any quantity, and which even here is limited, there being perhaps not enough for 100 years more.

The anthracite output is only about 10 per cent. of the entire coal production of the United States. At the present time, we are told, the output is larger than it ever has been; that the mines are producing a larger tonnage than ever with a smaller number of miners, who are working intensively. Fortunately anthracite will stock well, and this lends itself to easier methods of distribution than is the case with most soft coal.

The greatest problem is with the bituminous coal, and the sub-bituminous or lignitic coal mined in the far West. There are a great many varieties, each of which is fitted for special purposes. Most bituminous and sub-bituminous coal will not stock well. It cannot be put in large piles without danger of taking fire, and much of it when stored in piles of small height deteriorates rapidly, especially sub-bituminous coal. Hence, at the lake ports, there is only a limited storage of the better grades of coal, such as that produced in western Pennsylvania and West Virginia.

The highest grade of steam coal, corresponding with the Welsh steam coal, is the so-called "smokeless coal" produced in the Pocahontas and New River fields of West Virginia, and to a less extent in the Georges Creek, Maryland, and the central Pennsylvania districts. This coal is required for the warships, and for shipping. As it is important not to notify submarines of the approach of ships by columns of smoke on the horizon, smokeless coal should be used exclusively at this time by the allied ships; and if this causes difficulties elsewhere, persons and industries must suffer as a patriotic duty, using other coals of an inferior quality or of different character.

In normal times, its price at point of delivery controls the selection of a coal. Now, however, owing to the needs of the warships and transportation, readjustments must be made, which affect the intricate system of deliveries throughout the country, interfering with ordinary movements, so that consumers cannot always get the kind of coal that they have been used to, apart from the high prices.

The problem of the Fuel Administration is a terrific one; it is not only a problem of production, but also one of transportation. In general, it may be safely asserted that the mechanical capacity of the mines in

this country is amply able to take care of all its needs, but to obtain this capacity the mines must have sufficient railroad cars regularly to ship their output, and the loss of a day's output is one that cannot be made up. Some have imagined that coal can be stocked in the mine, but that is not possible, at least for more than a day's run.

It may also be asserted that there are enough men to produce the necessary coal, in spite of the diminished numbers, if they could and would work every day. "Could" means railroad cars and mine supplies; "would" refers to their willingness to stay on the job every day it is possible to work. The miners on the whole have been making large earnings, first because of the regular work that has been offered to them; second, because of the increases in the labor rates, which have been very large in some parts of the country. This has caused the indifferent miner to take self-appointed holidays when he should be at work. These are serious problems to the operators and to the coal administration.

Last winter, when coal was so scarce in the Pittsburgh district, the mines were able to work only about half-time because they did not have railroad cars for more. Later, through the help of the Coal Production Committee and the Transportation Committee of the National Council of Defense, some short-circuiting of the coal transportation was accomplished, and the production of the mines was materially increased. Still later, when the prices at which coal should be sold were determined by the Federal Trades Commission, and the operators in some instances feared they would lose money and the miners that they were not going to obtain further advances, there was a decided lessening of production.

This is what the new Fuel Administration has had to face, and we all hope that they may be able to work out the problems, in which they should have the help of every one, as the matter is one in which the entire country is vitally interested, both from the standpoint of winning the war and also from the point of bodily comfort in the homes.

Without sufficient coal, the railroads cannot transport the fuel and munitions of war; the munitions cannot be manufactured, and the shipping cannot obtain its fuel for transport of sailors and supplies. It calls for some sacrifice on the part of every one in the home to conserve his own fuel supply and avoid unnecessary heating; on the part of the operator not to spare supplies, and the investment of funds to increase facilities, although he may have a small margin of profit. It calls for the miners to forego pleasures which will keep them out of the mine during working hours—in other words, not to loaf but to stay on the job, for which they will receive full benefit by increased earnings at the highest rate that labor has ever known. This country has drafted its young men for the greatest sacrifice that a man can make. Is there any logical reason why all able-bodied males should not be compelled to do at

least 8 hr. work every working day until this war ceases, for which they will be paid far beyond what the man who makes the greatest sacrifice is paid? The enemy recognizes no restrictions of labor or time, so that the least that those of us who are at home can do is to stay on the job and put our hearts into it. The consumer may have to take a quality of coal that seems to him inferior, and it may cause him added expense to use it, but it must be remembered that any checking of the day's output for any reason is a loss which cannot be replaced.

DISCUSSION

[Instead of presenting his paper, as printed, Mr. Rice gave a brief illustrated lecture on the subject, the illustrations being largely maps of the coal fields in several parts of Europe, and graphic diagrams illustrating the production and consumption of coal throughout the world. He also showed photographs of several notable coal-mining plants in northern France, illustrating the devastation practised by the Germans on their retreat from that territory. It is not practicable to reproduce here either the illustration or the lecture.—*Ed.*]

EDWIN LUDLOW, Lansford, Pa.—For the first time in our history it has become the duty of the coal operator not only to practise the conservation of his own resources, but to preach conservation in the utilization of coal, by obtaining its full heat value. Coal operators in the past have been more interested in trying to mine coal at a cost that would enable them to keep their balance on the right side of the ledger, than in studying the full extraction of their coal resources. If they had done so in the past, only in favorable situations would it have been possible to mine and sell the coal in the competitive markets at a price that would return the cost of production. With the advance of prices and the demand for coal in excess of production, which is liable to last for many years, operators can now study more intensive methods for the complete extraction of the contents of their coal seams, with the security that their additional outlay and their higher costs will still net them a fair return on their investment.

With the higher cost of coal, it has also become a strong inducement for the manufacturer to pay closer attention to the results obtained from his boiler houses. In the past, coal has been so cheap that very little attention has been paid to scientific methods of firing, and to the full utilization of the B.t.u. in the coal purchased. A large manufacturer not long ago assured me that he was very particular about the purchasing of his coal, and insisted that all coal must be up to a standard of 14,600 B.t.u. In looking over his steam results, I called his attention to the fact that his coal should show an evaporation of 11 lb. of water per pound of coal, but that he was actually obtaining only 9 lb., and that by proper

firing he would make a saving of at least 20 per cent. in the quantity of coal he used.

In a large number of cases that I have had occasion to investigate, it has been found that the fireman is really the arbitrator of the quality and quantity of coal that is to be used, and that his methods of utilization are usually far from scientific.

It becomes the duty of coal men, when the opportunity offers, to call the attention of their customers to the conditions in their boiler rooms and point out to them how their consumption of coal can be decreased by more economical methods of firing and better boiler practice.

Mr. Rice speaks of petroleum and natural gas as being no longer available for fuel under boilers, on account of the much higher value and the great demand for the refined products of crude petroleum for purposes for which coal cannot be used. The consumption of fuel oil must, therefore, be replaced by coal both in manufacturing plants and on the railroads, and to meet this situation the utilization of inferior coals and lignite must be developed by mining engineers.

Recent development of large power plants located at the mines, for the generation of electricity and its transmission to distant places, points to the most available method for the utilization of a great deal of inferior coal now thrown away at the mines, or not now mined, that could still be economically used under proper boilers if no transportation charges were added to the cost of this fuel. In this way large electric units could be established adjacent to the lignite fields of Texas that would generate power to supply the industries now using fuel oil, and also would probably lead to the electrification of the railroads in the South, which are still large consumers of crude oil.

This plan has already been put in practice in the anthracite region for the utilization of the finer sizes that have heretofore been considered too small to be economically used under boilers, and approximately three to four million tons of fine coal is being thrown away each year at the anthracite mines. Briquetting permits the transformation of this fine coal into a domestic fuel equal, for many purposes, to the best grades of anthracite.

These large electric plants are now burning the finest size of buckwheat, which was formerly unsaleable, and are able to obtain a 200 per cent. rating on their boilers, and are sending out electricity at 110,000 volts to a radius of 75 miles. By doubling this voltage, it is estimated by electrical engineers that electricity can be sent at a less cost than fuel can be shipped to a radius of 200 miles, which would include Philadelphia and New York. The electric power required in these cities, instead of being manufactured at these points, could be more economically manufactured at a large central station located in the anthracite field. This development would relieve a tremendous congestion on the railroads in the handling of the fuel

needed for these large electric plants in the cities, and would be utilizing a grade of fuel that has heretofore been largely thrown away at the mines. The accumulation of this class of material in the anthracite region amounts to at least 25,000,000 tons, and is being added to each year at the rate of 2,000,000 to 3,000,000 tons.

In the general production of anthracite, the Pennsylvania fields have probably reached their maximum, with very little virgin territory left to be developed, and no large increase can be expected in the output of anthracite coal for the future from the Pennsylvania fields, except by the utilization of what is now being wasted.

George S. Rice (written discussion*).—An interesting and important question arose during the coal famine of last winter as to whether the development of new mines should be discouraged on account of the need of labor for the necessary construction and development work at a time of scarcity of labor, more especially as there was an apparent over-capacity of existing mines. The question was referred to the author for his comments, which led to the study of the statistics. The essential results of this study are indicated on the accompanying chart, which illustrates, among other things, the increase in production or consumption, and the estimated maximum production capacity of the bituminous and sub-bituminous mines of the United States. The curves shown are based on data published in the "Mineral Resources" of the United States Geological Survey, and cover the period from 1900 to 1916 inclusive.

The following curves have been drawn from the data secured:

1. Average number of days that the mines worked.

2. Yearly total production of bituminous and sub-bituminous mines.

2*a*. Yearly production of machine-mined coal.

3. Average annual production, equivalent to consumption, for a period of 17 years.

4. Number of coal mine employees each year.

5. Estimated capacity of mines, on basis of 300 working days in the year.

6. Estimated drop in capacity if no new mines are opened.

Considering these curves and the data from which they were constructed:

It will be noted that the average number of days the miners worked varied from 193 in 1908 to 234 in 1900, the average being 217. The causes for so many idle days out of the possible total number of working days in the year are well known, namely: (*a*) Lack of business; (*b*) lack of cars.

Taking the country as a whole, (*a*) is the important factor, which might otherwise be expressed as being an excess of productive capacity.

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* Received Apr. 4, 1918.

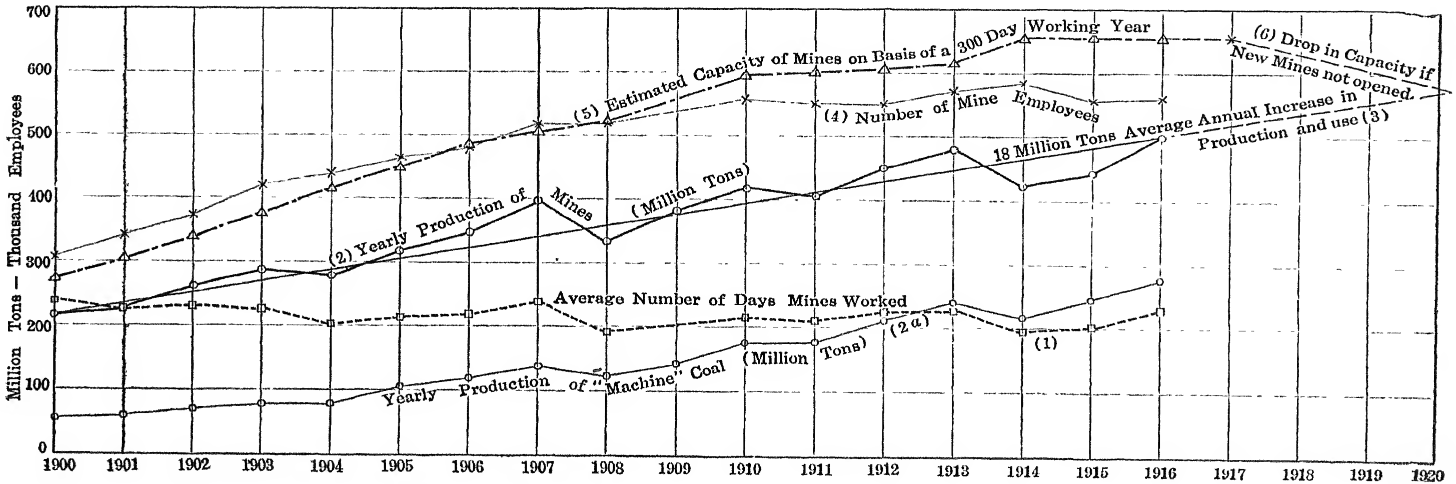

CHART ILLUSTRATING ANNUAL INCREASE IN PRODUCTION OR CONSUMPTION, ESTIMATED CAPACITY OF MINES, AND WORKING PRODUCTIVITY OF EMPLOYEES IN THE BITUMINOUS AND SUB-BITUMINOUS MINES OF THE UNITED STATES—ALSO SHOWING DROP IN CAPACITY BELOW CONSUMPTION IF NEW MINES ARE NOT OPENED.

(Production and labor figures from U. S. Geological Survey's "Mineral Resources.")

The yearly production of the mines, which is practically synonymous with consumption, has shown a steady increase, with a few set-backs. An average line has been struck which indicates that the average annual increase of production has been 18 million short tons (16,330,000 metric tons).

The number of employees steadily increased until 1910, then for the succeeding 6 years there was practically no increase. Fortunately, however, there has been a steady increase in the individual daily output of the bituminous and sub-bituminous mine employees, from a low point of 2.94 tons per day in 1901 to 3.91 tons in 1915. There was an insignificant falling-off to 3.89 tons in 1916. This increase in the individual capacity is unquestionably due to the greater introduction of undercutting machines and labor-saving devices.

Statistics of Bituminous Production in the United States. (Tons of 2000 lb.)

Year	Days Worked	Men Employed	Tons per Man-day	Total Production, Million Tons	Machine-mined Coal, Million Tons	Estimated Capacity,* Million Tons
1900	234	304,375	2 98	212	53	271
1901	225	340,235	2 94	226	58	301
1902	230	370,056	3 06	260	70	339
1903	225	415,777	3 02	283	78	378
1904	202	437,832	3.15	278	79	413
1905	211	460,629	3.24	315	103	449
1906	213	478,425	3.36	342	119	482
1907	234	513,258	3.29	394	139	505
1908	193	516,264	3.34	333	123	518
1909	(a)	(a)	(a)	380	142	(a)
1910	217	555,533	3.46	417	174	593
1911	211	549,775	3 50	405	178	595
1912	223	548,632	3 68	450	211	606
1913	232	571,882	3 61	478	242	618
1914	195	583,506	3 71	423	218	652
1915	203	557,456	3 91	443	243	655
1916	230	561,102	3.89	503	284	656

* If mines worked 300 days at same rate.
(a) Statistics not collected for the year 1909.

Curve (2a), showing the production of machine-mined coal, indicates a steady increase in the proportion of the total production. Whether or not further increases per mine employee may be expected remains an unsettled question, because the alleged drop in labor efficiency, due to tremendous increase in the unit prices paid labor, if true, may prevent future increase in daily output per employee through further introduction of labor-saving machinery and in this way curtail the total production until additional miners and laborers are available.

In estimating the maximum capacity of the mines in which labor and mechanical equipment are factors, it is possible, assuming ample transportation facilities, to work the mines 300 days in the year. Some well situated mines, especially mines owned and operated by railroads for their fuel supply, have done better than this, 310 days or over being reported. On the assumption that the rate of output for the days actually worked could be maintained for the remainder of the 300-day working year, curve (5) has been constructed. This indicates that the total possible productive capacity of the mines of the country has steadily risen at a rapid rate of about 32 million tons annually, until 1910. From then to 1914 the rate fell to 15 million tons increase, and for the years 1914, 1915, and 1916 it was practically stationary. It has been assumed that it was stationary in 1917.

An attempt has been made to obtain figures for the number of mines which are worked out and abandoned each year. The statistics gathered have been considered unreliable. The author, in order to arrive at certain approximate results, has had to make an assumption of the average life-time of a bituminous coal mine. From his own experience, and that of other mining engineers whom he has consulted, the assumption has been made that the average life-time is 20 years. If this is true, then one-twentieth of the mines are worked out and abandoned each year.

The Geological Survey compiled the number of mines, and the outputs for different sized mines, from 1909 to 1914 inclusive ("Mineral Resources"). This compilation shows that the ouput of mines producing over 10,000 tons annually was over 98 per cent. of the total production of the United States. The number of such mines and their output is as follows:

Year	Number of Mines with Outputs over 10,000 Tons Annually	Total Output, Million Tons	Average Output per Mine Tons
1909	3721	371.6	100,000
1910	3909	419 7	107,000
1911	3810	397.9	104,000
1912	3977	443.0	111,000
1913	4027	471.3	117,000
1914	3916	415.3	106,000

In 1913 (the highest figure), if 5 per cent. of the mines were worked out, then 201 mines, producing 23 million tons, ceased production.

On the basis of the average annual output as indicated by curve (3), if extended to 1917, the figure for the total output is 520 million tons, 5 per cent. of which is 25 million tons. This amount must be made up by the opening and development of new mines, in addition to which there must be enough other new developments to provide for the natural

increase in consumption, which it has been shown has steadily increased for 20 years at an average rate of 18 million tons per annum (curve 3). In other words, enough new mines to produce 43 million tons must be opened in 1918, and increasingly more during succeeding years to maintain a margin of capacity over consumption. This means that about 400 new mines, on the basis of previous assumptions, should be opened in 1918.

Assuming that the maximum capacity of all the mines on a 300-day basis for 1917 was unchanged from 1916 (the capacity for 1914 to 1916 inclusive apparently being stationary), and assuming that no new mines were opened after Dec. 31, 1917, then the line (6), which indicates a drop in capacity of 25 million tons per annum, would intersect the extended average consumption line (3) in 3 years, or at the end of 1920. As a matter of fact, it is probable that the estimated maximum capacity indicated on the chart could never be quite reached, on account of transportation difficulties. Hence, if no new mines were opened after Dec. 31, 1917, it is probable that inside of two years, or by the end of 1919, the consumption would have to be curtailed by reason of the estimated limitation of capacity of mines now shipping.

Fortunately, however, the situation was appreciated, and it is understood by the author that no governmental restrictions have been placed on opening new mines.

Coal and Iron Deposits of the Pen-hsi-hu District, Manchuria

BY C. F. WANG,* M. A., PEN-HSI-HU, MANCHURIA, CHINA

(New York Meeting, February, 1918)

CONTENTS

Introduction

Manchuria in General

Manchuria, called the "Three Eastern Provinces" in Chinese, forms the northeastern corner of China and is bordered by Siberia on the north and northeast, and by Korea on the east. It is a land famous in Chinese annals as the place of origin of the Ching dynasty, and in more recent times it has been an arena for diplomatic maneuvering and commercial competition between the Russians, advancing from the north, and the Japanese from the southeast. It derives its name of "three eastern provinces" from the fact that it is divided into three provinces; Hei-

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* Mining Engineer, Pen-hsi-hu Coal & Iron Co., Ltd.

lung-kiang at the north, Kirin in the northeast, and Fengtien at the south. The southern part of Manchuria is loosely called South Manchuria, but it has no distinct geographical boundaries, and no little confusion has been caused by the use of the term in diplomatic intercourse.

As a whole, Manchuria is a mountainous and cold country; the temperature in northern Manchuria in the winter often falls as low as -40 to -50 C. while in the southern part -20 C. is not uncommon. The Hei-lung-kiang, or Black Dragon river, forms the boundary between China and Siberia, and the Ya-lu-kiang divides it from Korea. The region to the south and west of these two rivers is rich in forests and mineral resources.

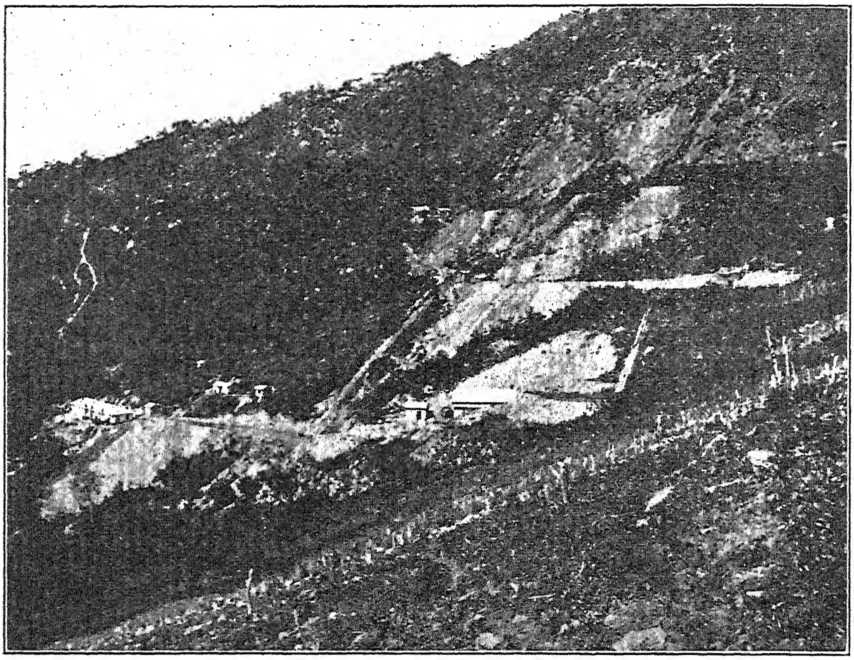


FIG. 1.—MIAOR-KOU IRON MINE, SHOWING THE THREE PITS.

Manchurian pine and other timber is extensively used in China, Korea, and Japan, competing with lumber shipped from the Pacific coast of America. The mineral resources, though yet far from fully developed, are likely to have political as well as economic significance in the future, because of their geographical position. In south Manchuria alone, I have personally seen many deposits of iron, coal, gold, and various non-metallic minerals. The great magnetite belt lies approximately in the central part of South Manchuria around Pen-hsi-hu as a center. It extends from northwest to southeast, beginning with An-shan-chang, Liao-yang prefecture, through Yao-chien-hu-tun, about 20 miles southeast of Mukden, where it disappears, and reappears in a great deposit at

Miaor-kou, about 67 miles southeast. Further southeast, it appears again at Ti-hsung-shan and at Tung-yuan-pu, Feng-huang-cheng prefecture. How much farther it goes is not known definitely. This will be described later in Section VI.

Magnetite and some hematite are found abundantly at An-shan-chang, on the Dairen-Mukden line, where a new joint company has been established. Other hematite deposits have been reported south and east of An-shan-chang; these deposits are found in various beds of different origin. Deposits of semi-bituminous, coking, and bituminous coals have been found near Mukden, at Yentai, Pen-hsi-hu, Niu-shin-tai and in the southeastern part of southern Manchuria. The two most-important companies are the Fushun Colliery, located about 10 miles east of Mukden, now worked by Japanese interests affiliated with the South Manchuria Railway, and the Pen-hsi-hu Coal and Iron Co., Limited. There are other places, as Niu-shin-tai and Yentai, but these are worked only to a small extent because transportation is difficult. Gold deposits are found in many stream beds near the contact between the igneous and sedimentary rocks along the line of the Dairen-Mukden railroad. There are other deposits north and southeast of Mukden. It is probable that gold-bearing veins will be found at the sources of these streams. Copper and lead are found at Antung and in the southeastern part of South Manchuria. Antimony and wolframite are found there also, besides large deposits of magnesite, talc, apatite, baryte, kaolin, and other associated minerals.

Pen-hsi-hu

Pen-hsi-hu is about 45 miles southeast of Mukden, the former capital of the Ching Dynasty (Manchu), before their conquest of China, and the present capital of Fengtien province, on the Antung-Mukden railway. This district was created in September, 1906, from four surrounding districts. It is the center of the great magnetite belt, as well as of the coal beds. The district was named after a little limestone-bordered pond where a stream of underground water flows out all the year around. Two hundred years ago this district was well known for its coal and iron industry, but owing to the underground water in the coal mines it progressively declined from about 1875 till the Russo-Japanese War. There were over 2000 people working there then. The ore for the iron industry was obtained from iron deposits at Miaor-kou, Niu-shin-tai, and Huo-lien-chai, and today the bottoms of the crucibles which were used for smelting iron by the native method,[1] can be seen in the street employed as bricks for building walls. Before the Russo-Japanese War this town was very prosperous, but after that, and together with the encountering

[1] T. T. Read: The Mineral Resources and Production of China. *Trans.* (1912), **43**, 27.

of underground water in the coal mines, both the coal and iron industries came to an end.

This district is surrounded by hills. The present standard-gage South Manchuria railroad line reaches Pen-hsi-hu after passing through three tunnels. There are altogether 24 tunnels on the Antung-Mukden line of 250 miles. Before this road was built, there was a narrow-gage railroad, winding around the hills, requiring over 3 days to travel from Mukden to Antung, but today the train traverses the same distance in 10 hr. South of Pen-hsi-hu is the important river Tai-tsu-ho, or Prince river, which passes here from Wei-tsu-yu in the east and winds southwest to Liao-yang. It brings down a good deal of sand. Many

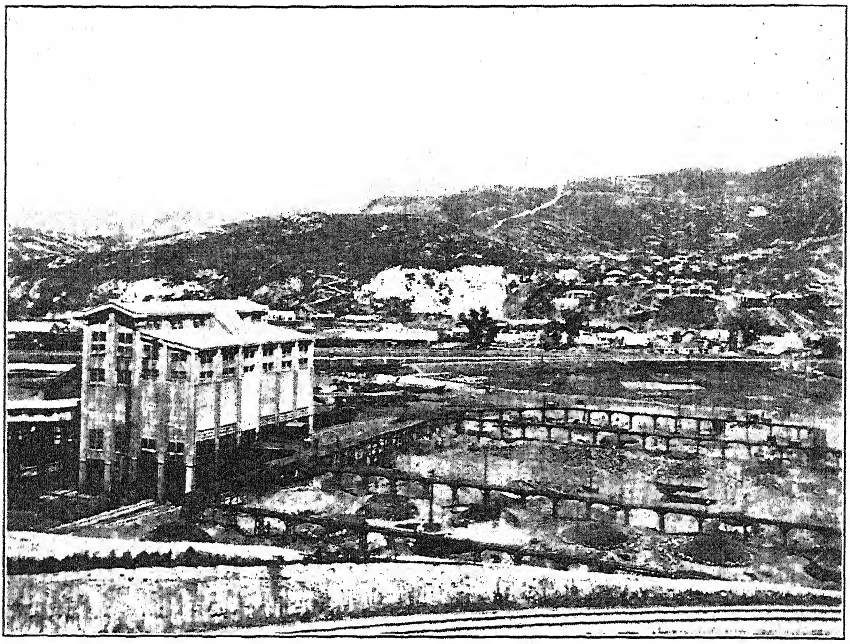


FIG. 2.—COAL WASHERY, COKING OVENS,

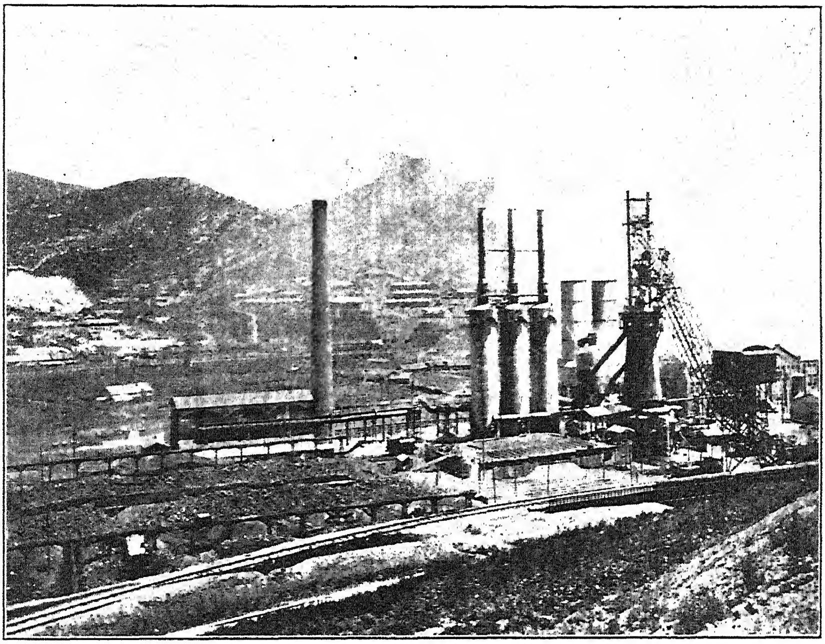
water wheels can be seen along the river for grinding millet and other grain.

Pen-hsi-hu has a population of over 10,000 Chinese, with over 3000 Japanese people in addition. The Japanese railroad section is well laid out, while the Chinese city is still in the unorganized stage. The residential section for the Japanese railroad employees is situated here, and they, with the merchants, swell the population to 3000. There is also a camp of soldiers in the eastern valley.

The chief rocks here are the coal formation, limestone, sandstone, and shales. They are of Carboniferous age, with rhyolite porphyry at the eastern hills, which cuts across the coal measures.

Pen-hsi-hu Coal and Iron Co., Ltd.

After the Russo-Japanese War, in October, 1905, Count Okura began to re-open the abandoned coal deposit. It was worked without Chinese permission for several years, until 1908, when H. E. Hsu Shih-chang, the Governor of Fengtien Province, proposed to combine Okura's interest with Chinese capital to form a joint international company. The company, with a capital of $2,000,000 silver, began operations as the Pen-hsi-hu Coal Co. In 1911, the Miaor-kou iron deposit was located, and in August, the incorporation of the Pen-hsi-hu Coal and Iron Co., Ltd., with a capital of $4,000,000 in silver, $2,000,000 from



RESIDENTIAL SECTION, AND BLAST-FURNACE PLANT.

each party, was completed. In 1914, an increase became necessary for building the second blast furnace, and the company increased the capital to $7,000,000, approximately equal to $3,500,000 gold. At present this company has coal mines producing over 1000 tons of coal per day, limestone quarries, a coal-washing plant, a coking plant of about 300 tons daily output, a blast furnace of 150 tons capacity and an iron mine at Miao-er-kou producing about 300 tons a day. A second blast furnace is being put up at Pen-hsi-hu. A concentration plant is to be erected at Nan-fen, near the main line of the railway, and a briquetting plant for fine iron ore and concentrates. In the near future, a coking plant will be built, and also a steel plant.

II. Organization

This is perhaps the first joint company between Chinese and Japanese. The organization is based on the principle of giving equal participation to both in the personnel. It is therefore to a certain extent a duplicate

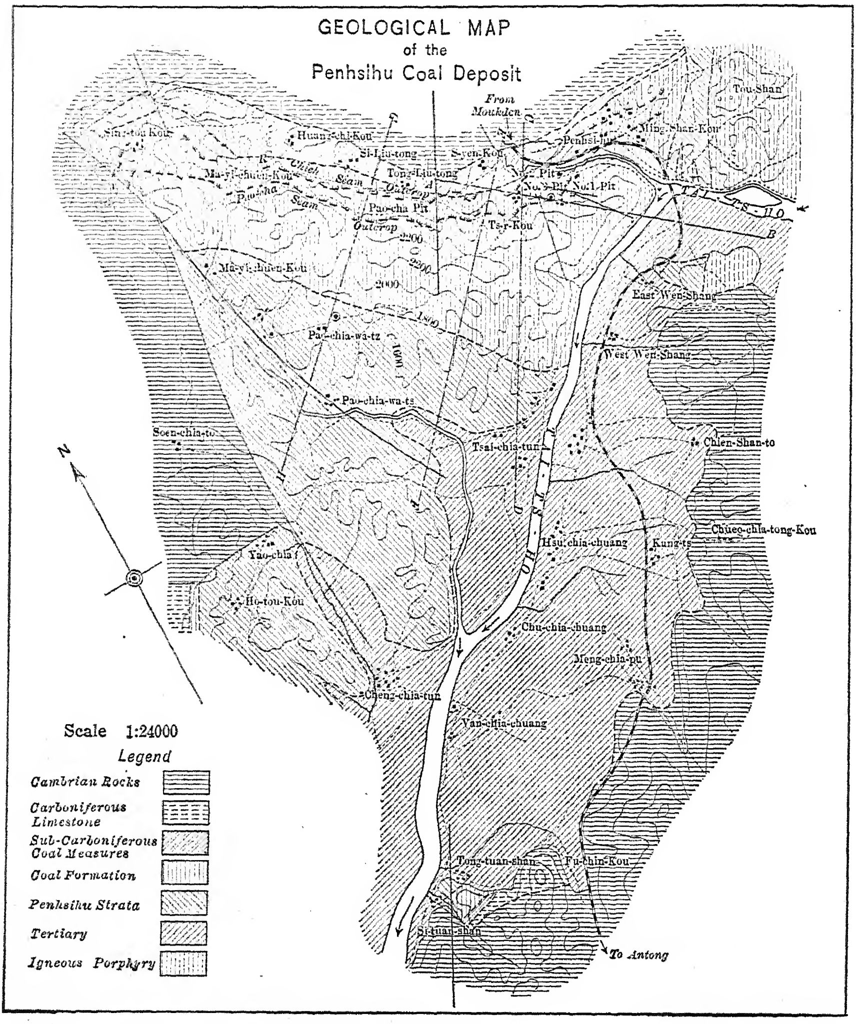


Fig. 3.

system, which means more or less waste both in energy and expense. However, it tends to show in a general way that so long as one nationality is not seeking too much advantage over the other, a formal coöperation can exist; and there is certainly much to promote friendship. Ac-

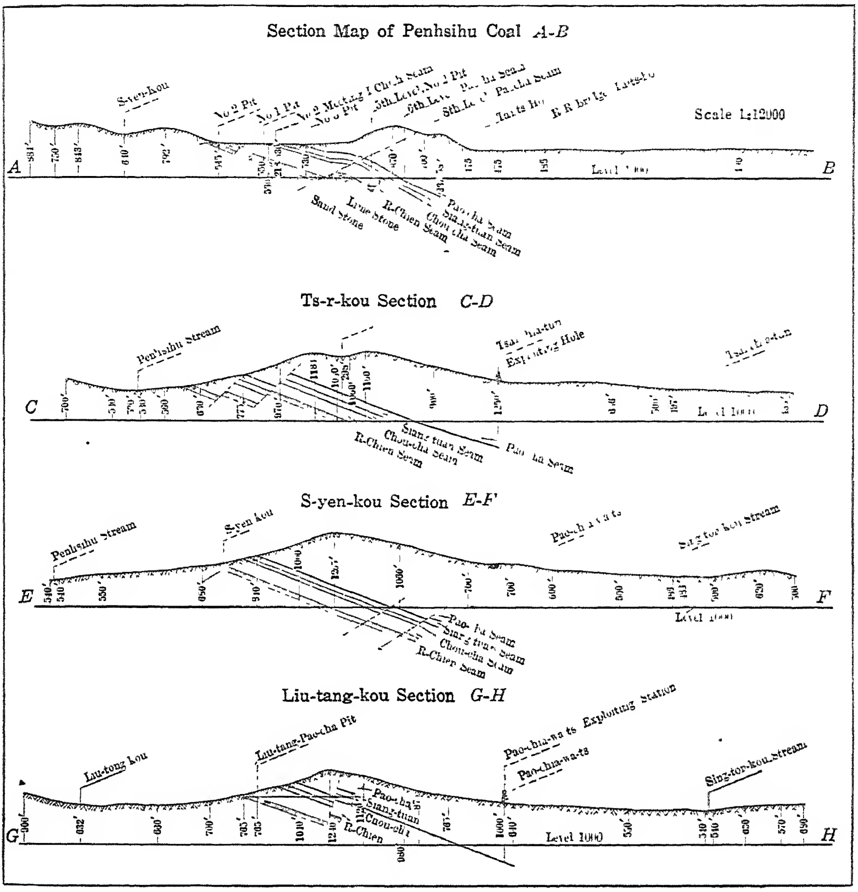


FIG. 4.—SECTION OF PEN-HSI-HU COAL FORMATION.

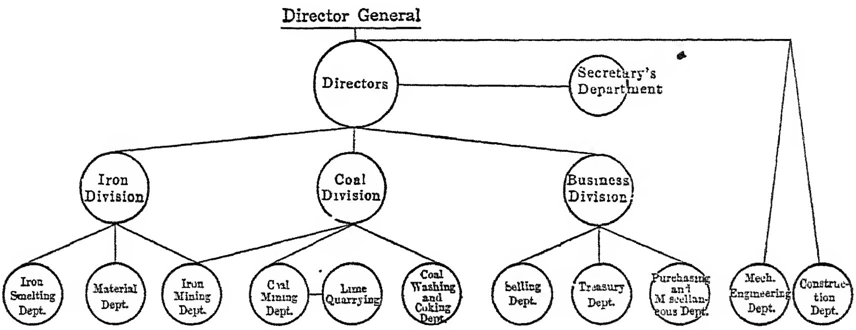


FIG. 5.

cording to the agreement, the chiefs of different departments, chief engineers of the three divisions, and directors are to be represented by both Chinese and Japanese. The first and third are represented in this way, but as for the divisions, the directors decided in January, 1916, to provide only one man for each. It is clear that unless the two men coöperate, conflict is unavoidable. However, the present system seems to work very well. In order to settle any disputes that may arise, and, in a way, to have general oversight of the joint company, the Commissioner for the Foreign Office at Mukden is Director-General ex-officio. Two-thirds of the employees are Japanese, while almost all the laborers are Chinese. In comparison with either American or European companies of this kind, or even with Chinese enterprises, the wages paid to the employ-

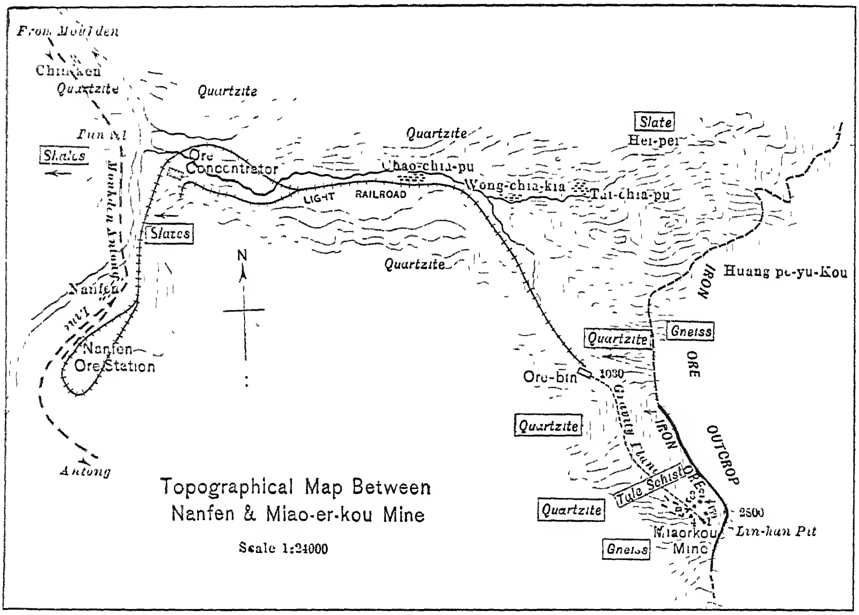


FIG. 6.

ees are low, but the standard of living and the dominant patriotic mood seem to make them adequate to produce a sufficient supply of labor.

The chart in Fig. 5 shows the organization in a general way.

III. Coal Deposit

Location

Near Pen-hsi-hu are great coal beds. The Tai-tsu-ho passes here from the east, and begins to turn southward at the foothills along the divide between the igneous rocks, of rhyolite-porphyry, and the coal formation, along a north and south line. The Mukden-Antung line crosses this stream with a 19-span bridge, then turns sharply toward the west to the station at Mukden. The company's land is between the hills

to the south and the railway line. The coal mine is about ½ mile west from the station. It is reported that approximately 18,000,000 tons had been taken out before the Russo-Japanese war (1904). The old shafts were not over 150 to 180 ft. (45 to 54 m.) deep, at which depth water was encountered. Numerous shafts were sunk, but all were abandoned.

Geology

The coal formation occupies an area of about 3400 acres between the Cambrian rocks and the Tertiary strata, with the igneous rhyolite-porphyry at the eastern corner. The latter disturbed the formation a good deal, by tilting and faulting. The limestone at the north extends under the coal formation, dipping from 20–50° south, southeast. At Pen-hsi-hu, the upper part of this coal formation has been cut away by a stream joining the Tai-tsu-ho at the south, forming the valley of Pen-hsi-hu. The coal formation consists of sandstone, sandy shales, shales, and coal beds, interbedded, of various thicknesses. It extends over 3 miles south. At the western boundary of the limestone, the hills attain their highest elevation, about 1800 ft. (548 m.) above sea level. Outcrops of coal are noticeable along the hills. Fossil prints of Carboniferous tree leaves can be seen distinctly in the shales. The formation may be divided into three fields, with sandstone as cover, then shale and sandstone interbedded, and under that limestone of crinoidal origin. The coal formation reappears again at Chien-chan-tse, after having been cut through by the igneous rhyolite-porphyry, and at Ya-Tsu-yu, to the east, forms another coal basin. The western area, extending from Sin-tung-kou to Ho-tung-kou, lying above the Cambrian rocks, amounts to 2893 mou or 444 acres (179 ha.) area, and has from 25 to 40 ft. (7 to 12 m. (total coal. There are many old inclined shafts there. The dip is around 25° to the southeast. The Liu-tong area has about 1135 acres (7390 mou) and 38 ft. of coal, while the Pen-hsi-hu area has about 1825 acres (11,900 mou) and 38 ft. of coal. The dip is about the same as in the western area. The total estimate for this 40 ft. of coal in the 18 beds of the three regions, is about 225,650,000 metric tons. Minus 17,992,000 tons reserve and on the basis of 60 per cent. recovery, for 1,000,000 tons a year production, there is a reserve for at least 120 years. S. S. Loh, according to a recent estimate, after careful study, gives the conservative estimate of over 123 million tons, as shown in Table 1, considering the coal beds at the average thickness of 25 ft. He divides the coal into five regions and divides each region into two sections, the upper and the lower section; the former of 6 ft. and the latter of 19 ft. in. thickness. Table 1(*a*) is taken from Koo Long's book, which gives in a general way the thickness of each seam as found near the surface. Mr. Loh has found that these seams decrease a good deal in depth.

Owing to intrusion by the igneous rock at the northeast, at Tou-shan, and faults in the limestone at the west, the coal formation is much dis-

TABLE 1.—*Coal Area and Tonnage at Pen-hsi-hu*

	Acres			Tonnage		
	Upper Seams	Lower Seams	Total	Upper	Lower	Total
Pen-hsi-hu	486	744	1,230	4,030,500	21,515,593	25,546,093
S-yen-kou	382	401	783	3,353,562	11,454,511	14,808,073
Liu-tang	388	425	813	3,496,056	12,282,175	15,778,231
Sing-ton	394	479	873	3,570,732	13,565,800	17,136,532
Vertical Shaft	1,318	1,318	2,636	11,963,964	37,695,886	49,659,850
Total	2,968	3,367	6,335	26,414,814	96,513,965	122,938,779

TABLE 1(*a*).*—*Thickness of Coal Seams in Feet*

Seam	At Pen-hsi-hu		At Liutong		At Shintong
	Ft.	In.	Ft.	In.	Ft
Pao-cha	7†		7†		6†
Siang-tuan	4	5	4	5	5
Chou-cha	3	5†	.....		5
I-Chieh (No. 1)	7†		8†		7†
Erh-Chieh (No. 2)	5†		8†		6†
San-Chieh (No. 3)	4		4		3
Ssu-Chieh (No. 4)	3†		4	5†	3†
Wu-Chieh (No. 5)	4		4		5

* From Koo Long's book "China Ten Minings" (in Chinese), Chap. 9, page 37.

† Coal hard and lumpy, while the rest are for the most part easily crumbled to dust.

turbed. As a result of the many faults and folds, the coal is of a semi-bituminous nature. The sandstone cover, of good-sized grains, is yellowish-white in color, and is good for rough building purposes. The shale is from very dark to light in color. This is the great Nan-fen shale, as it appears most prominently at Nan-fen, 17 miles southwest of Pen-hsi-hu. The coal formation has a total thickness of 500 to 550 ft. (152 to 167 m.) with eighteen seams of coal; eight of them are workable. Under this coal formation is sandstone again, some 20 ft. in thickness, then 20 ft. of shales; thus connecting up with the crinoidal limestone, which appears at Shun-shan-tsu, east of the company's land. The rhyolite-porphyry is dark gray in color and is hard, with orthoclase, hornblende, microcline, and quartz. Outcrops of coal can be seen on Shun-shan-tsu hill and to the west of Pen-hsi-hu station.

Coal Mining

There are three coal mines at Pen-hsi-hu. A fourth was abandoned on account of excessive water. They are all worked to the dip of about 20°. Levels are established 262 ft. (79.8 m.) apart, along the incline, or about 110 to 130 ft. (33.5 to 39.6 m.) vertically. No. 1

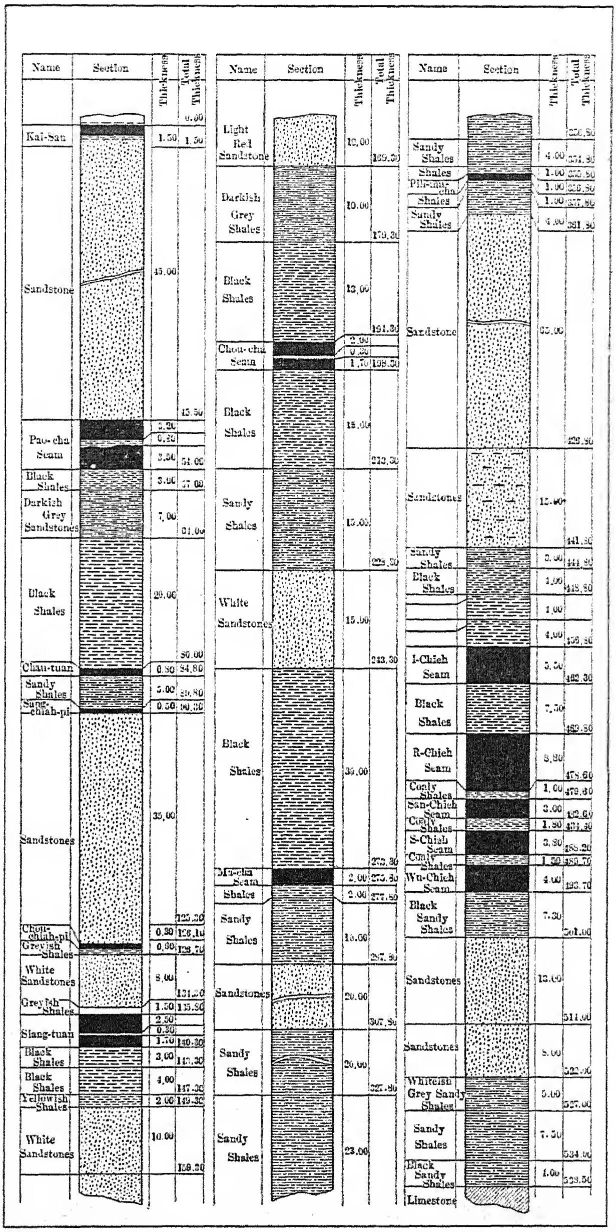


FIG. 7.—VERTICAL SECTION OF PEN-HSI-HU COAL DEPOSIT.

pit was first started in April, 1906, on the Chou-cha seam, which has the Pao-cha and Siang-tuan seams above it, a total of about 15 ft. coal. Three inclined shafts were simultaneously sunk for this No. 1 pit for haulage, drainage and ventilation, and manway. The haulage shaft has reached 2240 ft., of 6 by 10 ft. cross-section; the drainage and ventilation are taken care of by one inclined shaft, reaching 2352 ft., of 6 by 10 ft. cross-section; and the manway, reaching 3042 ft. from the surface, is 6 by 8 ft. in cross-section. There are nine levels in this No. 1 pit, 268 ft. apart. Coal is stored at the sixth and ninth levels, where it is loaded on cars, hauled by an endless rope driven by a cross-compound endless-rope engine having a steam pressure of 70 lb. with 14-in. cylinder, 150 hp., speed 120 r.p.m.

The No. 2 pit was started in October, 1907, about 200 ft. (60 m.) below the Chou-cha seam, along the second seam, which, with the first seam, constitutes about 12 ft. of coal. It was shut down for a year or so, but resumed working in March, 1909. It has two main inclined shafts; namely, haulage, which is 7½ by 12 ft. cross-section and 2336 ft. long at present, and manway, 6½ by 8 ft. cross-section, 2964 ft. long. Beside this, No. 2 pit has two upcasts for pumping water and one shaft for sand flushing. The two upcasts of 8½ by 11 ft. cross-section, are 140 ft. and 306 ft. long and the flushing shaft is 36 ft. deep. There are six levels in this pit, and the coal is accumulated from No. 2 to No. 6 level. The haulage system is the same as in No. 1 pit, except that it is electric driven, 150 hp., 150 r.p.m. by a 60-cycle, 2100-V., 720-hp. motor.

In the No. 3 pit there are eight levels. All coal is dumped from the third to the eighth level. The three inclined shafts, the haulage, drainage, and ventilation, and manway have 3000 ft. (914 m.), 3180 ft. (968.8 m.) and 2130 ft. (649 m.) respectively. This pit was driven in October, 1909, to facilitate transportation when the No. 1 pit's production was curtailed on account of the long distance. It is in the Pao-cha seam, which is the uppermost seam and has a thickness of 7 ft. Later it joins the No. 1 pit with a winze at about 580 ft. from the surface. In cross-section the haulage and manway shafts are 6 by 10 ft. and 6 by 8 ft. respectively. All inclined shafts are wooden timbered. The upcasts in the No. 2 pit were begun in May, 1913, with red bricks, with the aim to pump out all the water from the mine and provide ventilation. It was designed to put in two electric fans of 11 ft. (3.3 m.) diameter with a capacity of 160,000 cu. ft. (4530 cu. m.) air per minute, 6-in. (15.24-cm.) gage pressure from 150-hp. motor. It connects No. 2 and No. 4 pits.

Some exploring work has been done at Pao-cha-wa-tse by means of a diamond drill. It is a Harked and Allcocks Patent, steam-driven, diamond core drill including one steel angle derrick and one steel "Hopwood" boiler (water-tube type)—total cost Yen 16,480 ($8240 gold) with a total weight of about 15 tons; capacity 1800 ft. depth with 2-in. core.

It is expected that the Pao-cha seam will be found at about 1100–1200 ft. The boring speed varies according to the nature and hardness of the rocks. One speed is from 4 to 10 ft. per 12 hr. The new work at S-yen-kou will be started as soon as transportation facilities are completed.

Mining Method.—The method of mining employed is both longwall and bord and pillar systems. At present the latter is more generally used, but in the case of the first and second seams, which are close together and both thick, the longwall system has proved a failure. The use of the bord and pillar system, with sand filling flushed in as a support, was begun in 1916. The first recovery by this system is only 18 per cent., but the second working yields over 40 per cent. The method is shown in Fig. 8. The cross galleries are driven in the direction of the end (to the dip) and the working galleries along the face, at right angles

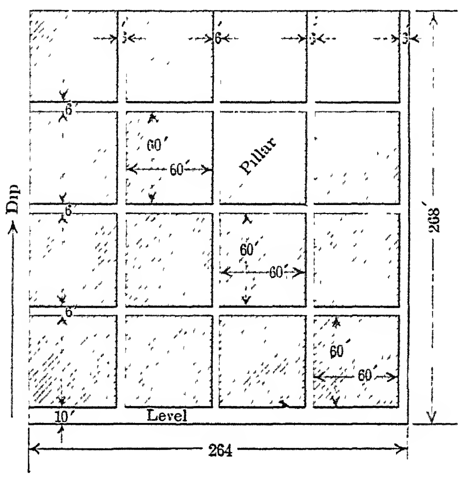


FIG. 8.

to the dip. Whenever there is a change in the dip, the working gallery makes a corresponding departure from its straight course. For flushing, sand, broken stone, or blast-furnace slag is conveyed through tubes with water under sufficient pressure to fill up the robbed space gradually from the third or fourth seam upward. Two crushers with 18-hp. and 50-hp. motors, and a 3-hp. pump are located at the surface. Pines or winter evergreen of 6 to 8 in. (15.2 to 20.3 cm.) diameter and 6 to 7 ft. (1.8 to 2.1 m.) long are extensively used for timbering purposes. They are bought at 2½ to 3½ c. silver per foot. Arthur Koppel roller-bearing coal cars of 25 cu. ft. (0.7 cu. m.) capacity are used, each car holding about half a ton of coal. A good deal of water is standing in the mine. The present drainage is about 200 cu. ft. per minute. Twenty-six pumps of various capacities are used in the coal mining. All mining is done by hand; no dynamite is used except for crosscuts. Gas is present, so safety

lamps have to be used. Mining is done by contract according to the production. The shift is 12 hr., from 4 a. m. to 4 p. m. There are about 1500 miners in the coal mine alone. The coal cars from the mine are sent directly to the washing plant by endless-rope haulage.

TABLE 2.—*Output of Mine*

Year	Tons (2240 lb.)
1911	126,086
1912	149,463
1913	270,782
1914	301,014
1915	306,516
1916	373,927
Total	1,527,788

The daily output for 1917 is about 1200 tons.

TABLE 3.—*Mining Cost, Jan. to End of June,* 1917

	Silver
1. Office expense	$0 406
2. Cost of levels—driving crosscuts, etc.	0.628
3. Boring	0 012
4. Mining	1.284
5. Washing	0.178
6. Machinery	0.600
7. Depreciation	0.048
8. Taxes	0.207
9. General expenses	0.398
Per ton coal, total	$3.762

TABLE 4.—*Analysis of Coal at Pen-hsi-hu*

No	Name of Coal	Water, Per Cent	Volatile Matter, Per Cent	Carbon, Per Cent.	Ash, Per Cent	Sulphur, Per Cent.	Calorific Power	Seam Thickness	
								Ft.	In.
1	Pao-cha	0.10	17.72	70.88	11.30	0.707	8,442	6	7
2	Siang-tuan	0 10	15.96	71.74	12.20	1.375	8,742	4	2
3	Chou-cha	0.00	21.56	67.04	11.30	1.333	9,042	3	7
4	I-chieh	0.20	18.16	72.92	8.72	2.093	9,042	5	5
5	Erh-Chieh	0.10	17.00	51.40	31.50	1.399	7,842	8	8
6	San-chieh	0.10	21.02	47.74	31.04	0.996	6,642	3	
7	Ssu-chieh	0.10	20 74	60.52	18.64	1.758	8,442	3	8
8	Wu-chieh	0.10	18.60	52.71	28.59	0.905	7,242	4	

IV. COAL-WASHING PLANT

The coal from the mines contains a good deal of shale and pyrite, amounting to a total of about 26 per cent. The analyses in Table 5, direct from the mine, show two extreme cases.

TABLE 5.—*Analysis of Crude and Washed Coal*

No.	Water	Vol C	Fix. C	Ash	Sulphur	Cal.	Remark
1	0.10	17.72	70.88	11.30	0.709	8,442	Before washing
6	0.10	21.02	47.74	31.04	0.996	6,642	Before washing
1	0.49	14.94	79.50	8 56	1.16	8,200	After washing
6	0.42	16.68	76.00	7 32	1.63	7,670	After washing

However, most of the coals are of No. 1 type, as shown in analyses No. 1, 2, 3 and 4, given in Table 4.

The coal from the mine is dumped through tipples to a moving screen which separates the size above and under 50 mm.; the oversize passes to a traveling metal belt which distributes the coal to a shaking table perpendicular to it. Men standing at both sides of the table sort out the rock and the clean coal goes to the bin, to be loaded on the outgoing train. This oversize constitutes about 19 per cent. of the total coal, of which 14 per cent. represents the coal proper, the rest rock and sulphur balls. About ½ per cent. of this oversize coal which is crushed to fine dust on the table is sent to the fine coal bin without any further washing. The sizes up to 50 mm. are elevated by means of bucket elevators to the top floor of the washery, and from there they pass through a series of shaking screens which separates four sizes; egg, walnut, pea and fine dust. These sizes are then passed through sets of jigs; the egg, walnut, and pea sizes are sent to a 6-mm. screen jig, while the fine dust is further divided into two grades, 10 to 6 mm. and 6 to 0 mm., with 12-mm. and 8-mm. screen jigs respectively. Twelve jigs are used, distributed as follows: 2 jigs for egg and nut, 2 jigs for pea size, 2 jigs for 10 to 6-mm. size, 4 jigs for 6 to 0-mm. size, and 2 jigs for rewashing purposes.

Feldspar is used for the secondary screen. The sizes are: 30-mm. size for 6 to 10-mm. coal, 30 to 25-mm. size for 6 to 0-mm. coal.

TABLE 6.—*Jigs*

Size	Mm.	Screen		Head	R.p.m	No. Jigs
		Screen	Feldspar			
Egg	30–50	6 mm.	....	200 mm.	56	2
Nut	18–30	6 mm.				
Pea	10–18	6 mm.	....	160 mm.	56	2
Fine	10–6	12 mm.	30 mm.	20 mm.	146	2
Dust	16–0	8 mm.	25–30 mm.	16 mm.	146	4
Rewashing	....	8 mm.	25–30 mm.	16 mm.	146	2

The washing plant is worked only in the daytime. It can handle 85 tons per hour. There are 20 men in each shift, and the washing cost, not

including the repairing of machinery, amounts to about 5 c. silver or 2½ c. gold per ton. The picking cost is 20 c. gold per ton. The sizes above pea are sold, while only the fine coal is used for coking purposes. About 21 per cent. of the coal from the jigs is ash, with about 5 per cent. in the oversize (above 50 mm.) forming a total of about 26 per cent. Most of the ash is in the dust coal, which is reserved for selling and for coke of poor grade. There is no crushing of the coal in the process, though recently the walnut size is crushed for experimental purposes, and gives a much better coke. The coal-washing plant is a complete concrete building which cost $270,000 silver. It has two sets of motors:

	Hp	Volt.	Cycle	R p m.
For washing coal	182	2,100	60	1,700
	18	2,100	60	1,750
For pumping water	120	2,100	60	720
	7.5	2,100	60	720

All water used is from the mine, and is first pumped to a reservoir.

V. Coking Plant

Pen-hsi-hu coal is of good coking quality. The washed coal from the washer has the analysis shown in Table 7.

Table 7.—*Analysis of Washed Coal*

No.	H_2O	Vol. C	Fix. C	Ash	S	Calories
1	0.10	17.72	70.88	11.20	0.707	8,442
2	0.10	21.56	67.04	11.80	1.333	9,042
3	0.20	18.16	72.92	8.72	2.093	9,042

Owing to lack of capital, the coking method still used is the native one.[2] The coking heaps consist of two frustums having the two large ends joined at the ground surface. The diameter of the large end is from 24 to 30 ft. and the small end 16 to 20 ft. The drawing (Fig. 9) shows one of the pits now used for producing over 300 tons of coke per day. It indicates also that the Chinese method is wasteful, but under such conditions, it may be adopted. The capacity of each pit varies according to the size and the total thickness of this double frustum. They vary from 70 to 85 tons capacity and can produce 45 to 54 tons of coke; the yield averages about 60 to 65 per cent. This indicates that about 15 per cent.

[2] See Yang Tsang Woo: The Manufacture of Coke in Northern China. *Trans.* (1906), **36**, 661.

of the coal, beside the volatile carbon, is consumed in coking. The coke runs from 16 to 25 per cent. ash, the coke ash having the composition shown in Table 8:

TABLE 8.—*Analysis of Coke Ash*

	SiO_2	Al_2O_3	CaO	MgO	Alkali	Fe_2O_3
Lump coke..	50.50	39 30	2.20	0 80	2 9	4.30
Coke dust . ..	53.75	35.46	2.05	0.98	2 65	5.14

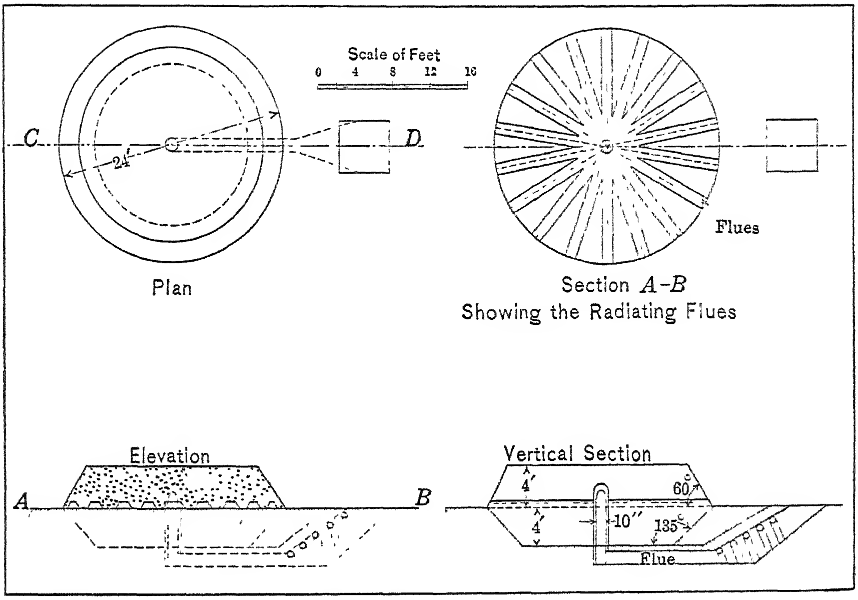


FIG. 9.—PEN-HSI-HU NATIVE COKE OVEN.

Coke for the blast furnace has an average of about 20 per cent. ash; that above this percentage is sold for domestic purposes. Dust coal can be used in making it.

Construction of Pit

The pit is cleaned first, and the draft passage cleared of water. Fine coal is then laid around a draft chimney of about 10 in. (25.4 cm.) diameter, which is built up by means of lump coal to about the surface level. Then the coal is leveled; 16 or 18 horizontal draft channels radiating from the central chimney are laid with stones of 9 by 6 in. cross-section. Some burning wood is put into the draft chimney and the lid closed at the top, then more coal is dumped on top, making an inverted cone over the bottom one. This is left until fire is seen to be coming out, the pit is then covered with stones and ashes to prevent its burning away. When

a blue flame is seen, the pit is finally fully covered up with ash. The coke when ready is quenched with water poured over the oven. It takes about 2 to 3 days for building up such an oven, 10 to 10½ days for coking, depending upon the weather, one day cooling with water and one more day for unloading the coke; total about 14 to 16 days. Each oven can produce 96 to 105 tons of coke every month. At present there are over 80 ovens, which produce about 250 tons per day. When the second blast furnace is built, over 100 more ovens will have to be built. It requires about 30 men for a 12-hr. shift to build one oven. The coking is all done by contract. A general idea of the number of laborers required for each process is as follows:

	No of Men
Loading coal to oven.	10
Getting stones	5
Covering and unloading coke	20
Water quenching.	1
Total	36
Production	70 tons

The average working cost per ton of coke is 54 c. silver or 27 c. gold. Last year the average working cost was 45 c. silver. Table 9 shows a record made in 1913; practice has not changed much since that time.

TABLE. 9.—*Labor Cost for Native Coking.*

Case No.	Loading Coal Men	Getting Stones, Men	Covering Ash, Men	Water, Men	Unloading, Men	Total Labor, Men	Burning Days	Total Days	Total Cost per Pit $, Silver	Cost per Ton Coke $, Silver	Total Pit Capacity	Total Coke Production	Percentage, Coke
1	29 0	10	4	1	23	61.0	10	14	21 35	0 59	67.68	36 18	58
2	32.2	12	6	1	26	81.2	9	15	28.32	0 68	68.10	41.60	61
3	26.0	10	6	1	41	88 0	11	17	30.80	0.79	66.72	39.11	58
4	22.5	12	5	1	40	82.5	7	16	28.87	0.67	65.56	45.24	69
5	18.5	6	3	1	32	60 5	10	15	21.17	0.54	66.30	39.35	60
6	31 0	6	4	1	28	68 0	12	18	23.80	0.51	76.89	46.83	60
7	27.0	12	6	1	39	85.0	15	21	29.75	0.41	115.00	70.86	61
8	31.0	8	5	1	22	57.0	12	18	19.95	0 41	79.50	48.00	64

The gases are, of course, not utilized, but this is the most economical way to make coke under the existing circumstances. A modern byproduct plant of 60 ovens will probably be erected in 1918. The coke is of good quality; it is grayish-white, not so silvery white as some cokes, and is hard and strong. Its only disadvantage is its high ash content, which is the more objectionable because it contains so much alumina. The net cost of coke per ton at present, including the cost of coal mining, washing, and overhead, is $7.80 silver or $3.90 gold per ton.

VI. Iron Deposit

Magnetite Belt

The great magnetite belt in Fengtien Province is extensive in area and the deposits are of large size. Near Liao-yang, at An-shan-chang, poor ores—from 30 to 50 per cent. Fe—occur mostly in the form of magnetite in layers with quartz. Near Yao-chien-hu-tun, at Wai-tou-shan, the ore is 40 to 50 per cent. Fe. Magnetite, dipping 45° west and about 100 ft. (30 m.) thick, lies between quartz-porphyry and gneiss. At Miaor-kou, the ore zone is 300 to 600 ft. thick, including two rich veins, 50 and 33 ft. thick respectively, and 66 to 70 per cent. Fe. The ore lies

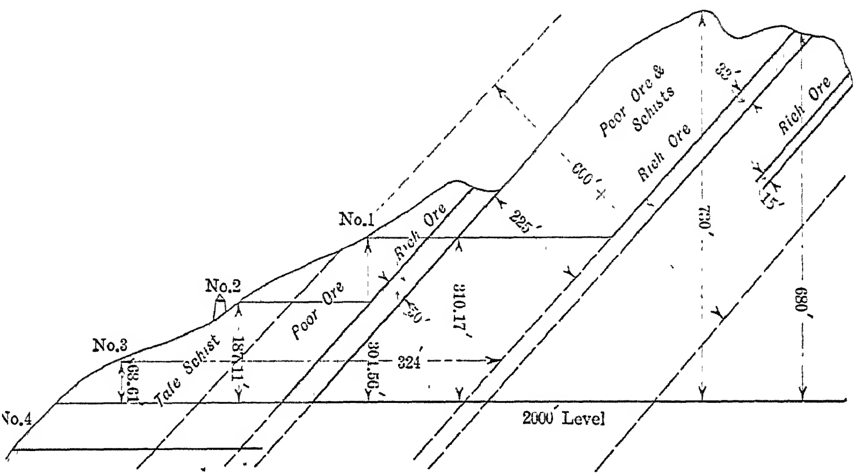


Fig. 10.—General section across *A–B* (east–west), Fig. 11.

between walls of talc-schist. Above the talc-schist is gneiss and quartzite. The tunnel intersects pure white talc-schist, chlorite schist, poor ore, and finally the rich ore. The rich ore is so far known to be about 480 ft. long and 50 ft. wide, narrower at the middle and ends. At present there are three levels 120 ft. apart and a fourth level is being driven. A cross-cut from the first level cuts the eastern rich vein, the Ling-nan-k'eng, or Ling-nan pit. Two other rich veins of 15 to 25 ft. exist further east of the Ling-nan pit. This ore belt at Miaor-kou can be traced north for about a mile from where the ore bin is located, at the point where the gravity plane connects with the light railroad. There must be two faults or more; one cutting the talc-schist which here forms the eastern hill with the quartzite appearing in the opposite hill a few feet away. No gneiss can be seen except to the east, where the quartzite

lies above the gneiss; a little further east the gneiss predominates. Here along this valley, there must be a second fault. The ore disappears, reappearing in the southeastern hills at Hei-shan-pei. Most of this ore is low grade, it can be traced for over 4 miles, roughly speaking. On a conservative estimate, the orebody at Miaor-kou, with about 500 ft. now developed, must contain over 100,000,000 tons, of which about 2,000,000 tons is 60–70 per cent. Fe ore. In the hills to the west of Ch'ao-ho, at Ti-hsüng-shan (Brothers' Hill), another magnetite body occurs. The magnetite there, dipping about 45–50° west, lies between rhyolite-porphyry and talc-schist, which is of wide-spread occurrence in this part of the country. The orebody is about 30 ft. wide and extends a few hundred feet, dipping about 65° southwestward. The eastern side has better ore, but it is lower in level. This ore has been worked for over 80 years by the natives and about 250 tons of the ore per year is smelted at Sai-ma-chi for manufacturing agricultural implements and home utensils, in a small cupola furnace 6 ft. high and 2 ft. in diameter. No limestone is used, the coke is 2:1 of iron ore by volume. Between the rhyolite-porphyry and the granite in the valley with the Ts'ao-ho running at the middle, gold is found in the gravel. Ten miles further westward, at Tung-yuan-pu, 30 miles southeast of Nan-fen, or about 40 miles southeast of the Miaor-kou deposit, the magnetite body is again found. It is darker in color between gneisses. It is about 30 ft. wide, dipping 30° west and about half a mile long. A conservative estimate of the orebody here is 1,000,000 tons of ore of about 60 per cent. Fe. I have found poor ore also at Hsiao-hei-shan, 2 miles east of Tung-yuan-pu, and at Fan-chai-tai. All these are associated with gneiss and talc-schist. There are probably other places of which I have not been informed, or have not yet found. In a general way, this great magnetite belt probably contains over 500,000,000 tons of ore, including rich and poor, associated with talc-schist and gneiss.

Origin of Deposit

As mining has been done for only a few years, the geology has not yet been studied extensively. It is difficult to ascertain the origin of this deposit, but I shall recite some of the facts that appear to bear on its origin. There is an immense amount of tilting, faulting, and folding in the country between Chiao-tou and Feng-hwang-cheng. The quartzite appears here, shales there, then the quartzite again and so on. Between Nan-fen and Miaor-kou, a distance of 5 miles, there are a great many faults. In the iron deposit itself, it is evident that the orebody has been stressed by an immense amount of pressure and tilting, for it has thin laminations of quartz and magnetite crystals and in places is distinctly folded. The magnetite is crystalline and is grayish in color. It is

not thoroughly disseminated through the quartz and can be separated from it by washing, which suggests the feasibility of concentration by means of water. In the poor ore, magnetite is laminated with quartz. The ore contains pyrite in crystalline form, as good-sized cubes. It is observed that the pyrite increases somewhat in depth. It is more abundant in certain places, but not evenly distributed in the ore. The contact between gneiss and talc-schist is not very distinct. The talc-schist near the gneiss contact is very white, while the schist near the ore is penetrated with magnetite and hornblende crystals. In the chlorite schist, octagonal crystals of magnetite are often found. In the rich ore we find thin lenses of asbestos. This evidence lead me to believe that the ore-body at Miaor-kou is most likely a residual deposit which was later concentrated by the agencies of metamorphism. The two rich orebodies, as they are situated in the ore belt, are most likely due to magmatic concentration. It is difficult to conceive this large orebody as having originated from iron sulphide, because most of the pyrite we find is in well-defined cubical crystals. They are not found scattered in massive form, but only in small veins and cracks, in cubes. It is true that it increases somewhat with depth, but not to any large extent, and should this ore have originated from sulphide, we should find pyrite less crystallized and more abundant. Again, the lamination in the orebody indicates a residual origin. It has undergone great pressures. There are no igneous intrusions, so far as known. The magnetite found at Ti-hsung-shan is along a contact between porphyry and metamorphic talc-schist. The ore at Tung-yuan-pu exhibits specific differences in comparison with either Ti-hsung-shan and Miaor-kou, and occurs in gneiss; the roof rock is white gneiss with a little hornblende.

TABLE 10.—*A Few Analyses of Ore at Miaor-kou*

No Ore	Fe	Fe in Fe_3O_4	Fe in Fe_2O_3	SiO_2	Al_2O_3	CaO	Mn	S	P
1. Rich	71.12	69.15	1.97	3.29	1.52	Tr.	0.067	0.278	0.016
4. Poor	59.75	56.79	2.96	20.17	1.679	Tr.	0.100	0.052	0.050
2. Poor	38.83	33.87	4.96	40.33	2 89	0.033	0.085	0.035	0.048
7. Poor	33.87	26.10	7.76	47.80	2.96	.....	0.083	.....	0.054

Mining

Mining was first started on the outcrop of rich ore, along the dip, but later three levels of 120 ft. (36.5 m.) apart were driven to the western rich body. The open-cut mining is done during the summer time, as the excessive coldness in the winter renders such work impossible. Overhand stoping is used in the underground work. No machines or machine drills are used—all the drilling is done by hand; dynamite and nitroglycerine are used as explosives. The roof rock, which is low-grade ore

here, is very hard and so is the orebody itself. No timbering is used except at the drift entrance. Massive rooms of 80 to 100 ft. each way and some 60 ft. high are worked without any support. Precautions are taken to blast down all ore or poor ore that is attached to certain cleavage planes. In the 3 years' record, only one accident has happened, when a block of the roof, about 80 ft. square and 5 to 6 ft. thick, fell and killed 13 men. The rich ore is crystalline and is friable, 10 to 20 per cent. of the mined ore being fine dust. This suggests the necessity of a briquetting plant to agglomerate this fine dust into bricks that can be charged to the blast furnace. The mining is done under three foremen who each have at present command of 250 to 400 men, working 12-hr. shifts when driving drifts. At midday, when the shots are fired, the miners have 2 hr. for luncheon. The men are paid according to the

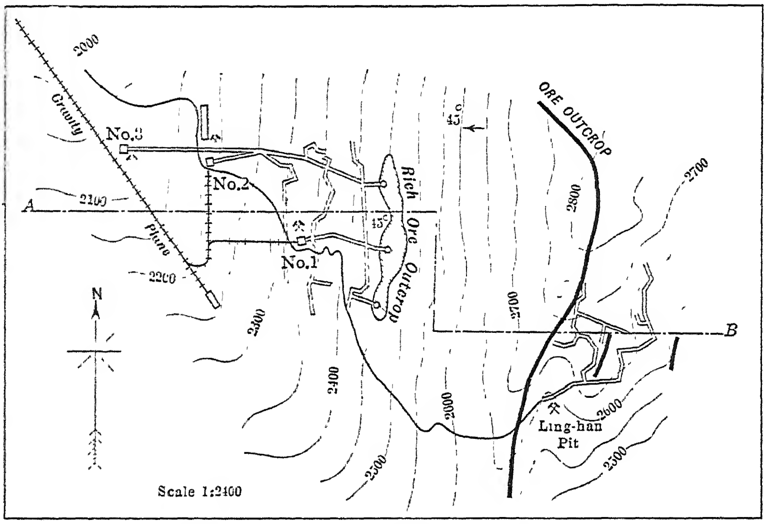


Fig. 11.—Plan of Miaor-kou mine.

number of cars of ore mined or number of feet advanced, and the men in a gang, mining, transportation, miscellaneous carriers, etc., all receive equal pay for the total output made by the gang, as shown on the books of the company; a redistribution is afterwards made by the foreman. The cost of explosives, food, drills, lamps, and oil is deducted at the end of each month; usually corresponding to net wages of 45 to 50 c. Mex. per day. The rate assigned for each car of lump and fine ore and for advancing drifts, etc., is made out by the engineers in charge, according to the character of the ore and rock. For lump ores, from $1.70 to $2.40 silver is paid per car of 1.65 tons, or $0.66 to $0.925 silver per ton, for fine ore from $0.85 to $1.20 silver per car of 1.8 tons, or $0.66 to $0.925 silver per ton. In drifts of about 7 ft. cross-section, every foot of advance costs from $13 to $25 silver. The following is an illustration of

mining costs, for April, 1916. The total mining cost ran from $1.35 to $1.00 per ton.

	Mexican, per Ton
Driving drifts and exploration work	$0.205
Lump ore mining	0.886
Fine ore mining	0.073
Blacksmith work	0.015
Underground transportation	0.173
Total mining cost	$1.352

In the above mining cost, about 45 per cent. represents the cost of the explosives, of which the price has more than doubled, on account of the European war. About 48 per cent. of the mining cost is for labor, and the rest for tools, repairs, etc. During the same month, the general ore cost was as follows:

	Mexican, per Ton
General expenses	$0.138
Mining	1.352
Machinery	0.057
Narrow gage R. R	0.443
Storage of ores at Nan-fen	0.019
Tax (according to fine and lump ore)	0.077
Transportation to Pen-hsi-hu	0.447
Total	$2.533

The summit of the hills is 2800 ft. (853 m.) above sea level. The ore is being worked from three drifts, now a fourth one is being driven, as well as a cross-cut to connect with the eastern rich orebody, or Ling-nan pit. The ore is transported down to the ore bin at the 1100-ft. level in the valley by means of a self-acting gravity plane. This has a total length of 6200 ft. and a grade of 20 to 25°. A new controlling machine yields a good deal of compressed air that can be used for air drills which we hope to install in the near future. The rope is 1¼ in. and 19-wire seven strand. The narrow-gage railroad has a gage of 20 in. and is 5 miles long. A new branch is being built to connect the road to the coneentrator, at Nan-fen. The iron ore production was as follows: In 1915, 51,672.04 tons; in 1916, 71,753.30 tons.

VII. Concentration Plant

As I have mentioned already, the major part of the deposit at Miaor-kou is composed of poor-grade ore, running from 30 to 55 per cent. iron. As around 75 to 80 per cent. of the ore is in the magnetic form, and the quantity is so large, a concentration plant for treating it is necessary. This plant is now being erected at Nan-fen, near the railroad station, and will have a capacity of 150 tons per 12 hr. The poor ore is brought

in by the narrow-gage railroad on the eastern hillside to the ore bin, from which it runs into a jaw crusher of 620 by 325 mm. aperture. This crushes the ore to about 1.5 mm. From here it goes through two Gröndal magnetic separators; the magnetite is picked up and separated, the tailings proceed to the classifiers to be sorted into three grades, the heads are sent to the main flow, tailings to waste and the middling pumped back to be re-concentrated on tables. The product from the first Gröndal separators is re-ground with water, in a tube-mill having a diameter of 1.3 m. and length of 5 m., by means of steel and gravel balls, to under 0.07 mm. The ground ore is allowed to run through another set of two Gröndal separators, which are exactly similar to those of the first set. The concentrate from this set is sent to shaking troughs, together with the incoming heads from the tables; from there they are discharged to the railroad cars by means of an overhead crane. The non-magnetic product from the second set of the magnetic separators is pumped to the tables for further concentration. There may be slight changes in the flow sheet, but this is the plan which we expect to follow. From the description above, it is evident that no roasting is required because the ore is magnetic and the gangue rock quartz. Perhaps it will prove to be cheaper to concentrate this magnetite by means of water alone, as experiments made by Professor Edwin A. Sperry of Pei Yang University and myself indicate that water separation is very effective, and it is far cheaper.

VIII. Briquetting Plant

The concentrates from the Nan-fen concentration plant, the fines obtained from the rich ore mined (as this ore is very brittle), and the flue dust from the blast furnaces, are all three mixed in the briquetting plant. This plant is also in the course of construction at Pen-hsi-hu, near the blast furnace. It will consist of two Emperor presses to make bricks of 6¾ by 6¾ by 2¾ in. (171 by 171 by 69.8 mm.), one Sutcliff's patent tunnel kiln 230 ft. (70 m.) long and 6 ft. (1.8 m.) cross-section. The kiln will be heated by means of two gas producers, until the briquettes are dry and hard. It is intended to use half concentrate and half rich-ore dust, with a small amount of limestone as cementing material.

Chemical Laboratory

The chemical laboratory is simply an analytical laboratory. The samples analyzed are about the same every day, except once in a while, when some samples other than coal, coke, pig iron, and iron ores are brought in. It needs no special description here.

IX. Blast-furnace Smelting

The first blast furnace was completed in December, 1914, after 1 year's work for erection. The plan of the company is to build eight

blast furnaces and a steel plant. A second blast furnace is approaching completion this winter. The No. 1 blast furnace was built by Pearson, Knowles & Co., of England, at a cost of $2,400,000 (silver) for the whole equipment. It is 83 ft. 3 in. (25.3 m., 7.6 cm.) above ground level, with two exhaust stacks of 75 ft. 9 in. (22.8 m., 22.8 cm.) high, standing above the charging level. The distance between the charging level and hearth bottom is 65 ft. 7 in. (19.8 m., 17.7 cm.). The hearth diameter is 9 ft. $10\frac{1}{10}$ in. and 7 ft. $10\frac{7}{16}$ in. high. The bosh is 17 ft. $8\frac{1}{2}$ in. diameter and height 14 ft. $7\frac{15}{10}$ in. The diameter of the furnace tops is 11 ft. $1\frac{1}{2}$ in. The cubical capacity of No. 1 blast furnace is 10,279.34 cu. ft. The second blast furnace is of similar dimensions and of similar design, but is slightly larger in capacity, being 7 cu. ft. bigger. It is being built by the Dairen Sa-ho-k'ou Iron Works from pieces brought from the United States, Japan, and Hanyang Iron and Steel Works because

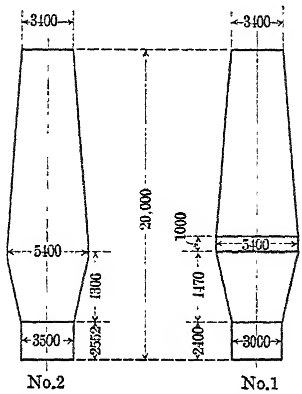


FIG. 12.—PEN-HSI-HU BLAST FURNACES, SECTIONS IN MM.

of the war. The furnace has two sets of tuyeres, one above the other, with nine tuyeres of $4\frac{3}{4}$ in. diameter each. The upper set was intended for emergency use, but it was later found better to use both of them. The charging is done by an inclined hoist with a charging bucket of 2 tons capacity. It has a length of 164 ft. with an inclination of 51°. The dynamo is 37 hp. There are three hot-blast stoves for No. 1 furnace. They are of the McClure type (three pass), each 90 ft. high (27,432 mm.), 20 ft. (6095 mm.) in diameter, furnished with a stack of 70 ft. (21,316 mm.) high and 6 ft. 3 in. diameter (2057 mm.). The discharge valve of the hot blast is 8 ft. 8 in. (1143 mm.) above the floor. The air is supplied by two turbo-blowers, each having a capacity of 16,000 cu. ft. per minute at 4 to 7 lb. pressure per sq. in. at 3000 r.p.m. They were made in Germany; one is used at a time. The set for No. 2 furnace will be from Switzerland. The second blast furnace is equipped with four hot-blast stoves of the same size; one will be held as reserve for emer-

gencies for either No. 1 or No. 2 blast furnace when a stove needs repairing. We have found that three blast stoves are quite insufficient to keep up a constant blast temperature, especially during the severe cold of winter; as around 40° C. below zero is not uncommon during December, January, and February. The blast can be adjusted with cold air to maintain an even temperature blast. The temperature used is from 600 to 650° C. depending upon the kind of iron produced. There is so much dust in the furnace gas that it is impossible to use it for heating under boilers; it is also injurious to the blast-stove bricks. The gas carries so much magnetite and lime dust that the firebricks melt down often after a few days of excessive heating, which is sometimes necessary, especially when only two stoves are operating.

A gas-cleaning plant will be installed with the second blast furnace. The gas from the furnace is first to pass through a dust chamber of spiral type (the dust chamber for No. 1 blast furnace is a two-cylinder type 8500-mm. by 6858-mm. inner cylinder dimension), then through a scrubbing apparatus where the gas is washed with water in fine jets. This gas-washing plant consists of one cleanser and one dryer for the gas from each blast furnace. The cleanser is 79 ft. 4¼ in. (24 m. 10.8 cm.) above ground, 58 ft. 2¼ in. (17.6 m. 5.6 cm.) high itself and 15 ft. (4.5 m.) in diameter. It has three sets of wooden baffles with four sets of eight 2½-in. water nozzles followed by two alternate sets of perforated steel tray and wooden hurdles in the path of the down-coming water. The gas is to enter at the bottom and travel upward. The dryer is a cylinder 14 ft. 8¼ in. long and 12 ft. in diameter, with two ends attached each to a frustum, making a total length of 21 ft. 8¼ in. for the dryer. It is intended to utilize the washed gas for heating boilers which are now being built behind the main power house. There are three boilers for washed gas and two sets of Wilcox & Babcock boilers for coal, in case of emergency. All the firebricks in the blast stoves and for the second blast furnace, except for the hearth bottom, are made by the Kailan Mining Administration, Tangshan, China. These bricks are fairly good. The forced-draft burner to the blast stoves was changed last year to insure quicker burning and a larger draw of free air from the atmosphere. It is patented in England by our department engineer, S. Sugimoto.

The slag is used for filling low areas of the company's ground. Recently we have been disintegrating the slag with a jet of water and using it for making slag bricks. The second slag notch is specially used for this purpose. The slag is mixed with one-fourth lime, ground in two Chilean mills, and molded by hand, either by men or women, into bricks. These bricks withstand crushing well and they set after 2 weeks' time; the longer the stronger. They are not burned and they cost about $7 silver per thousand, including everything, which is about the same price as the burned red bricks. Behind the furnaces is the ore

and limestone yard, which is connected by railroads. The limestone is now transported here directly from the quarry by means of aerial tram of over 6000 ft. (1828 m.) length. Each bucket holds ¼ ton weight, the total number of buckets being 70. To run this aerial line, a 36-hp. dynamo is used, but the line is mostly self-running by gravity. All trestles are made of wood. The cost was about $30,000 silver for this installation. The limestone costs about 70 c. per ton, or $0.35 gold. Coke is loaded on cars from the coking yard directly to the inclined hoist, taking 2 tons each time. The coke costs about $7 silver or $3.50 gold per ton, delivered at the charging station.

Some Notes about Iron Smelting

The first blow-in was made on Jan. 13, 1915. It was thought that hematite was necessary to mix with the rich magnetite for smelting; accordingly hematite ores from Kaisan, Angaku and Sainai, Korea, were bought. Some analyses of these ores are shown in Table 11.

TABLE 11.—*Analyses of Korean Iron Ores*

Ore	Fe	SiO_2	Al_2O_3	CaO	MgO	H	P	S
Rich ore.......	65.85	5.09	0 55	0 ·88	......	0 55	0.021	0.551
Kaisan ore	47.31	13.51	1 60	1.670	0.615	0.30	0.063	0.051
Angaku ore ..	49.97	21 67	1 40	1.14	0 688	0 50	0.034	0.73
Sainai ore.......	51.73	19 80	2.14	1.06	.....	....	0.069	1.53

These ores were mixed proportionally, but the output during 1915 was small. The high ash and especially the high-alumina ash in the coke, makes the slag high in alumina; as a result the slag became very viscous. At the same time, the blast stoves could not produce sufficient hot blast. This led the engineer in charge to think that since the upper set of tuyeres was still left idle, he would try to use the two sets together. The attempt was successful, and he began to improve the blast-stove burner because of the greater amount of hot blast required. In the latter part of 1915, and during April and May, 1916, exclusive use of magnetite was tried; for a few months a charge of 47 ore 14.5 limestone and 40 coke, producing a slag of 28.25 per cent. SiO_2; 25.13 per cent. Al_2O_3 and 41.27 per cent. CaO. The average production has been raised from 120 to 150 tons and over per day for 3 months, reducing the coke ratio from 1.5 to 1.1 per ton pig iron. But the pig iron produced is not of high grade. Owing to the use of both sets of tuyeres, the smelting zone has been pushed up; undoubtedly many explosions in the hearth can be attributed to this practice; but this high heat provides the heat required for such viscous slags. To bring the alumina lower and silica higher, siliceous ore (Kaisan ore) was again used to mix in, at the end of May, 1916. A

sudden drop of output immediately ensued, from 147 down to 109 tons per day, but gradually, with adjustment of charge, it again reached and then broke the record, 158 tons being averaged per day for a month in November. The slag has been brought to SiO_2, 30 per cent.; Al_2O_3, 19 per cent.; CaO, 44 per cent.; which is a much better slag to run with. The temperature of the blast also has been better adjusted, being around 650° all the time since June. The record shows clearly with temperature constant and other things remaining the same, that a slag of higher silica and lower alumina is a better slag. If the addition of Korean ore is nothing but a question of silica, there is no need of paying high freight rates to transport these low-grade iron ores from Korea, as we have more than plenty of low-grade magnetite at our disposal. The practice is now generally abandoned, and our own ores will be exclusively used from now on. In the short life of the first furnace, not yet two years, we have had many explosions below the slag-notch level, bursting the hearth cylinder through into holes. Also, we have some hang-ups, but usually they do not cause great inconvenience, as with some adjustment of the blast or otherwise they usually come down. I believe that the reason for such explosions, which are not common in other smelters, is two-fold; one, the high heat produced by the two sets of tuyeres and the other, the inverted hearth bottom. This can be noticed in the drawing. The remedy for this, I believe, is the calculation of a better slag charge; this will mean also that we should have lower-ash coke if possible. The sulphur content of that now used is another very objectionable quality. We make the slag very limy, around 50 per cent. CaO sometimes, in order to get out the high sulphur, as shown in Table 12.

Table 12.—*Analysis of Slags*

SiO_2	Al_2O_3	CaO	S
24.70	21.46	51.74	3.62
25.82	21.58	49.39	3.40
26.28	22.50	48.67	3 46

Table 13.—*Pig Iron Production*

	Total	Average per Day
1914	29,519.87 tons	97.07
1915	49,211.49 tons	134.46

Market

Over 85 per cent. of our pig iron is exported to Japan, while the home market at Mukden and Dairen, and the Chinese Eastern and South Manchuria railroads absorbs about 11 per cent., leaving a small amount for our own use.

In conclusion, I wish to express my indebtedness to Mr. S. S. Loh for the data on costs, to Professor Edwin A. Sperry of Pei Yang University for the use of photographs, and to the company for the drawings and maps.

DISCUSSION

The Chairman (Edwin Ludlow, Lansford, Pa.).—Mr. Wang's paper reminded me that some years ago I was asked if I would not go into the Tien Tsin district and take charge of Americanizing a Chinese mine. They said the trouble was that, while wages were only 9 c. a day, the coal cost $2 a ton delivered on the cars. Reading Mr. Wang's paper would indicate the need of a little Americanization in the Manchurian field where wages are only 40 c. a day, yet the cost is $3.60 a ton. An efficiency engineer would have an excellent opportunity in that field.

T. T. Read, New York, N. Y.—It is always true that low-priced labor is inefficient, wherever we find it; for example, in Japan, where wages are low, but not so low as in Manchuria, working costs are not relatively much lower than ours. Mr. Padshah, describing his experience in India, once told me that, while wages were only about one-fifth as high as in England, his output per man was only about one-fourth, so that he had only 20 per cent. advantage at Tata as compared with iron and steel work in England. Thus, in China wages are very low, but the output per man is also so low as to offset nearly the whole advantage of the low wages.

Possible Oil and Gas Fields in the Cretaceous Beds of Alabama

BY DORSEY HAGER,* TULSA, OKLA.

(New York Meeting, February, 1918)

THE possibility of oil and gas production in Alabama has been little considered as yet. Gas and some oil have been found in northwestern Alabama, near Birmingham, in the Pennsylvanian beds, but the oil and gas possibilities in the Cretaceous beds are not generally appreciated. The recent activity of oil companies in that State has attracted much attention, and in this paper the main structural and the general stratigraphic features are described. Four favorable areas are outlined. These contain folds of major interest. There are other favorable areas which have not been mapped.[1]

Commercial pools discovered in this area would have the advantage of being near tidewater. Mobile, Ala., on the Gulf of Mexico, would be the logical site for refineries and shipping facilities. A pipe line could readily be laid to that city from the Hatchitigbee and the Jackson areas. The logical outlet for the Geneva and the Gordon areas would be Panama City, Fla., on the Gulf of Mexico.

TOPOGRAPHY

The whole of the area under consideration lies in the Gulf coastal plain and slopes gently to the southwest and west. The elevations vary from 200 to 400 ft. (60 to 121 m.) above sea level. The streams have sunk their channels into this gently sloping plain, the main drainage flowing south or southwest into the Gulf of Mexico. Between the

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* Petroleum Geologist and Engineer.

[1] The writer owes acknowledgments to:

Eugene Smith, of the Geological Survey of Alabama, who described the Hatchetigbee anticline in *Water Resources of Alabama*, whose general résumé on the stratigraphy of Alabama has been used extensively.

Lloyd William Stephenson, whose *Professional Paper* 81, U. S. Geological Survey, "Cretaceous Deposits of the Eastern Gulf Region," has been freely used for his descriptions and correlations.

Lee Hager, of Houston, Tex., who first called the writer's attention to the Hatchitigbee anticline, and mapped the fold 10 years ago.

Wm. C. Spooner and J. R. Jillson, geologists in the employ of the firm of which the writer is a member, who made the reconnaissance surveys of the Jackson, Geneva, and Gordon folds. Field work was commenced in June, 1916, and completed in July, 1917.

streams are found remnants of this plain, constituting the hills of the area. The relief varies from a few feet up to 150 ft. in certain parts. The country is generally covered by timber.

STRATIGRAPHY

The thickness in the generalized sections presented must be considered largely as estimates, especially the thicknesses of the underlying Cretaceous beds, as no wells have been drilled deep enough to give good type sections. The Cretaceous sections mentioned were secured at the outcrop and in water wells at shallow depths. Away from the old shoreline of the Cretaceous, it is very likely that the beds thicken southward.

The comparative relations in Table 3 show the general correlation of the Louisiana and the Alabama formations.

TABLE 1.—*Generalized Geologic Section of Western Alabama*

Geologic Age	Group	Formation Name	Thickness, Ft.	Character
Pliocene-Pleistocene		Lafayette	25	Gravel, sands, clays
Lower Miocene		Grand Gulf	50	Soft sandstones and clays
Lower Oligocene		St. Stephens limestone	300	Unusually soft limestone, easily cut with saw
Eocene	Claiborne	Gosport greensand	30	Glauconitic sands
		Lisbon	115	Calcareous clays and sandy clay
		Tallahatta buhrstone	400	Aluminous sandstones and siliceous clays
	Chickasaw (Wilcox)	Hatchetigbee	175	Sandy clays and cross-bedded sands
		Bashi	80	Sands and clays. Fossiliferous green sand
		Tuscahoma	140	Gray and yellow cross-bedded sands
		Nanafalia	200	Siliceous clays
	Midway	Naheola	150	Gray sandy clays. Glauconitic clays
		Sucarnochee clay	100	Dark-brown clay
		Clayton	50	Impure limestone
Upper Cretaceous		Ripley	300	Calcareous and siliceous sands
		Selma chalk	950	Argillaceous limestones
		Eutaw sands	500	Glauconitic sands, cross-bedded
		Tuscaloosa	1,000	Irregular bedded sands, clays, and gravels

TABLE 2.—*Generalized Geologic Section of Eastern Alabama*

Geologic Age	Group	Formation Name	Thickness, Ft.	Character
Pliocene-Pleistocene		Lafayette	150	River terrace sands and gravels
Lower Miocene		Grand Gulf	50	Argillaceous Aluminous fine white sands, clays
Lower Oligocene		St. Stephens	90	Siliceous limestone and gray-blue sands
Eocene	Claiborne	Gosport greensand Lisbon	150	Glauconitic sands
		Tallahatta buhr-stone	200	Calcareous sandstones, fossiliferous
	Chickasaw (Wilcox)	Hatchetigbee	100	Limestones and clays
		Bashi	80	Sands and clays
		Tuscahoma	175	Gray and yellow sandstones
		Nanafalia	175	Sandy clays, fossiliferous
	Midway	Clayton	200	Limestones, fossiliferous
Upper Cretaceous		Ripley	1,000	Blue-gray calcareous sands and yellow calcareous hard sandstones
		Eutaw	150	Yellow green sands, clays, cap of phosphatic calcareous sand and rotten limestone
		Tuscaloosa	150	Purple, gray, red laminated clay, variegated colored sands, chert pebbles

TABLE 3.—*Comparative Geologic Section*

Geologic Age	Alabama	Louisiana
Eocene	Caliborne group.............	Claiborne group
	Wilcox group................	Wilcox formation
	Midway group..............	Midway formation
Upper Cretaceous	Ripley formation............	Arkadelphia clay Nacotoch sand (gas sand)
	Selma chalk.................	Marlbrook marl Annona chalk Brownstown marl
	Eutaw formation............	Eagle Ford clay
	Tuscaloosa formation........	Woodbine formation (Caddo oil horizon)

A study of the Tertiary formations from Louisiana to Alabama shows that these formations preserve their main characteristics, though presenting many variations in thickness. The Cretaceous, on the other hand, shows numerous changes in the character of the formation.

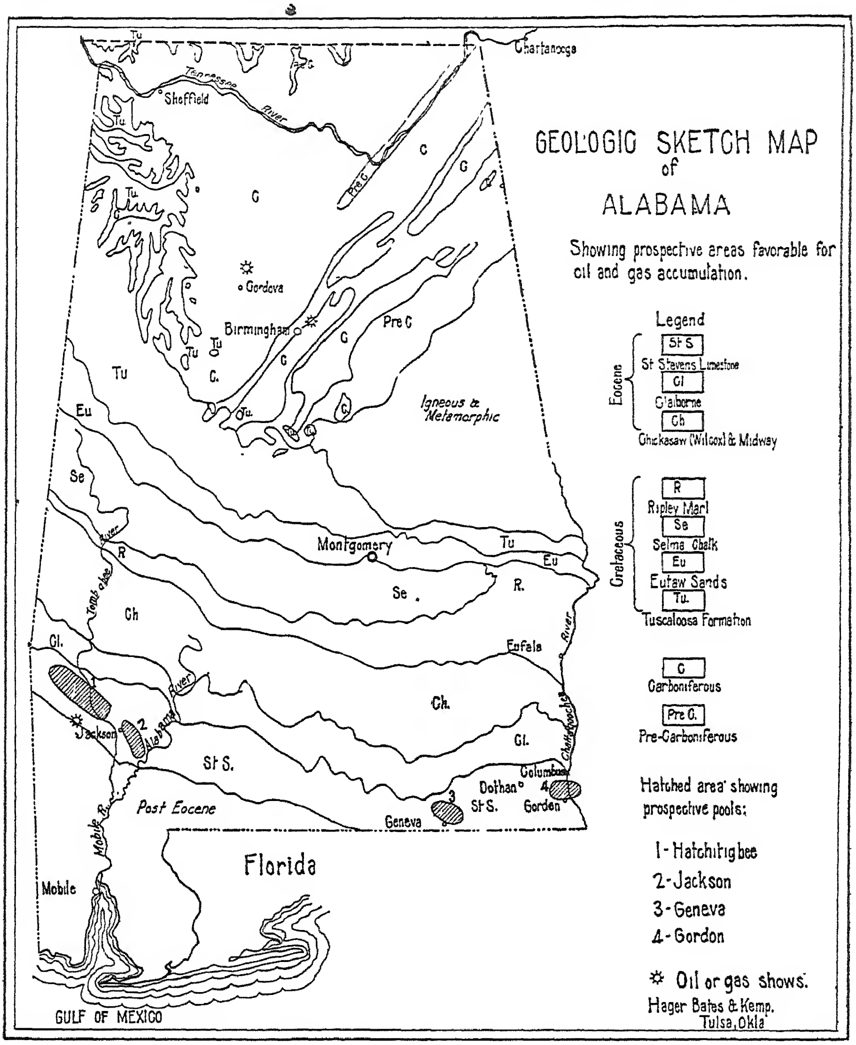

FIG. 1.

The larger portion of the area is unconformably overlain by the Grand Gulf formation, and all of the area by the Lafayette formation, of post-Tertiary age. These formations consist of thin-bedded and massive clays of varying colors, interstratified with sands, the latter in many places indurated or hardened to form sandstones. The St. Stephens limestone constitutes the uppermost member of the Eocene in

this area, and is the equivalent, in part, of the Vicksburg and, in part, of the Jackson limestone in Mississippi. In Alabama, it is difficult to differentiate these two formations. The limestones show many variations, being in some cases hard, almost crystalline, and of a variety of colors. Commonly the rock is soft, easily cut with an ax or saw, and is popularly known as "chimney rock." This formation has a thickness of between 200 and 300 ft. (60 and 91 m.), and is fossiliferous at certain horizons.

The Gosport greensand is a highly glauconitic sand, about 30 ft. (9 m.) in thickness, and is characteristic in this area. This sand abounds in characteristic fossils and is a reliable horizon marker all the way across the State. The Lisbon formation comes below the Gosport sand and has a thickness of about 115 ft. (35 m.), consisting of calcareous clayey sands and sandy clays, generally fossiliferous. In the western part of the State, the most prominent rocks of the Tallahatta buhrstone formation are argillaceous sandstones and siliceous claystones, always poor in fossils. To the east, the clays decrease and the rocks become calcareous and richer in fossils. This formation varies from 400 ft. thick in the western part of the State to 200 ft. in the eastern part. All these formations belong to the Claiborne group of the Eocene.

The Wilcox group is made up of Hatchetigbee, Bashi, Tuscahoma, and Nanafalia formations. The Hatchetigbee is the uppermost formation of the group and consists of about 175 ft. (53 m.) of brown, purple, and gray laminated sandy clay and cross-bedded sands, abounding in fossils. This formation extends to the east and maintains its characteristics. The Bashi formation, about 80 ft. (24 m.) thick, is composed of sands and clays. It is distinguished by a bed of highly fossiliferous greensand, with associated beds of lignite immediately below it. The Tuscahoma formation, about 140 ft. (42 m.) thick, consists mainly of gray and yellow cross-bedded sands and sandy clays, generally poor in fossils. The Nanafalia formation is 200 ft. (60 m.) thick. The beds of this formation are generally sandy but contain a great number of *Gryphea thirsae*. To the east, siliceous clay beds are indurated into rock closely resembling the Tallahatta buhrstone. At the base of this formation there is a bed of lignite 5 to 7 ft. (1.5 to 2.2 m.) thick, which is continuous for a long distance across the State to the east.

The Wilcox group comprises the Naheola, the Sucarnochee clay, and the Clayton limestone. The Naheola formation consists of about 150 ft. (45 m.) of gray sandy clays, with some beds of dark sandy glauconitic clay, containing marine fossils near the base. This formation is not found along the Chattahoochee River, which is on the Alabama-Georgia line. The Sucarnochee clay formation consists of a series of dark brown clays at least 100 ft. (30 m.) in thickness. This formation is sparingly fossiliferous in a few localities. The clays become more calcareous to the

east. The Clayton limestone is at the base of the Tertiary and is found as a thin impure limestone in western Alabama; it is well developed along the Chattahoochee River. This formation has a thickness varying from 50 to 200 ft. (15 to 60 m.) of alternating calcareous sands and limestones.

Below the Clayton limestone of the Eocene is found the Ripley formation, belonging to the Cretaceous. This has a thickness of 250 to 300 ft. (76 to 91 m.) and is mainly sandy, but contains a considerable proportion of limestone and calcareous sands. This formation is the equivalent of the Arkadelphia clay and Nacotoch sand in northwestern Louisiana.

The Selma chalk, about 950 ft. (289 m.) thick, comes below the Ripley formation, and consists mainly of more or less argillaceous and sandy limestones, rendered chalky by the large content of foraminiferal remains, with interbedded layers of nearly pure limestone. This formation is represented in northwestern Louisiana by the Marlbrook marl, Annona chalk, and Brownstown marl.

The Eutaw sand is made up mainly of more or less glauconitic sands, massive to cross-bedded, with an estimated thickness of about 1000 ft. (304 m.). The Tuscaloosa is an equivalent of the Woodbine horizon in the Caddo field of northwestern Louisiana, where it is a prolific producer of oil. It appears in the section of western Alabama and is given in the section for eastern Alabama, although it may be absent under the Gordon fold.

Geologic Structure

The normal or regional dip of the strata, where undisturbed by folding, is 30 to 40 ft. (9 to 12 m.) to the south. Due to folding in the area here discussed, the dips vary from nearly horizontal to 150 ft. (45 m.) to the mile.

The main structural features described are the Hatchetigbee, the Jackson, the Geneva, and the Gordon anticlines (see No. 1, No. 2, No. 3, and No. 4 on the accompanying map). These folds belong to the true anticlinal dome type of north Texas and Louisiana, and not the saline dome type so commonly found in the Gulf Coast area of Texas and Louisiana.

The Hatchetigbee anticline is an elongated fold running in a general northwest and southeast direction through portions of Choctaw, Clarke and Washington Counties, and is about 20 miles (32 km.) long and 4 to 5 miles wide.

Along the axis of the Hatchetigbee anticline, the formation of the same name is found outcropping. This formation is about 550 ft. (167 m.) lower stratigraphically than the St. Stephens limestone, which outcrops on all sides of the fold. From this fact, we may draw the conclusion that the reversal is not much less than 500 ft. The pitch of the strata away from the axis of the anticline ranges from 1° to nearly

2°. The Jackson anticline is in all probability a part of the same fold as the Hatchetigbee anticline. Along the axis of the Jackson anticline, rocks belonging to the Claiborne group are exposed at the surface and the reversal is not much less than that of the Hatchetigbee anticline, from which it is separated by a saddle or low place (see accompanying map) along the fold.

Proceeding east, no marked folding is noted until Geneva County is reached. In an area near Geneva (see No. 3 on map), covering possibly 20 sq. miles or more along the Pea and the Choctawhatchee Rivers, the Claiborne rocks are again exposed at the surface with the St. Stephens limestone surrounding them. The reversal on this fold would not be less than 100 ft., and probably considerably more than this. In this area the exposures are very limited, due to the covering of the Grand Gulf and Lafayette formations.

It is probable that a more detailed reconnaissance will disclose similar folds in the area between the Jackson and the Geneva folds. Near Gordon, and east of Geneva, Ala., an anticline was discovered (see No. 4 on map). This fold extends across the Alabama line into Georgia. It has a measured reversal of 40 ft. (12 m.), and covers some 10 sq. miles (25.9 sq. km.). In all probability the reversal is no greater than measured. As would be expected from the size of the folding, there has been some faulting, but it is doubtful that there has been enough to affect the accumulation of oil and gas in this area. The magnitude of these folds is such that in the writer's opinion it is doubtful (if we take for granted the presence of oil) that all of the area embraced in these folds will be productive, but rather that cross-folding and minor anticlines and domes superimposed on the main folds will control the accumulation.

Prospective Oil and Gas Horizons

There is a possibility that the Ripley formation may produce either gas or oil, or both, in commercial quantities. There is a chance to obtain oil or gas in the Tombigbee sand at the top of the Eutaw formation. This sand is 150 to 200 ft. thick and forms a good porous medium. The Tuscaloosa formation, at the same horizon as the Woodbine sand in the Caddo field in Louisiana, is also expected to be an oil-producing horizon of this area.

A well now drilling on the Hatchetigbee anticline is reported to have had showings of gas at 750 and 1500 ft. and oil at 2250 ft. The 750 gas horizon is probably in the Ripley formation, and the 1500 horizon is somewhere in the Selma chalk. The 2250 depth is below the Selma chalk and probably in the Eutaw sands. A few other wells drilled for artesian water have reached varying depths, but none have penetrated to the deeper Cretaceous beds.

Possibilities of Oil in Other Horizons

In western Alabama the underlying Carboniferous beds should be reached at a depth around 4000 ft. on the Hatchetigbee fold. At the outcrop, the Lower Cretaceous beds are absent, and the Tuscaloosa beds lie unconformably upon the Paleozoic. The Carboniferous of western Alabama shows evidence of oil and gas, so it is not unlikely that oil might be found at the contact between the Cretaceous and Carboniferous, or in horizons below.

Some question of the possibilities of oil and gas may be raised on the grounds that the outcropping beds show no positive evidence of being petroliferous in character. That in itself, however, has little meaning. In Kansas, Oklahoma, Wyoming, Kentucky, Indiana, and Ohio, no positive oil or gas seepages occur near the outcropping beds of many of the producing fields. On such negative evidence, those fields would have been thrown out. The outstanding facts which must be considered are these: the sedimentary beds are of undoubted marine origin, and contain an abundant fossil fauna and flora, which are important if one accepts the organic theory. Important evidence is the finding of oil and gas in the Hatchitigbee anticline.

Summary

1. At least four anticlinal folds of considerable magnitude have been found in Alabama.
2. The stratigraphic features of Alabama resemble those of Louisiana.
3. The Ripley, Eutaw, and Tuscaloosa formations in Alabama possess possibilities of commercial petroleum deposits within range of the drill.
4. A well now drilling on the Hatchetigbee anticline has encountered gas at 750, and 1500 ft., and oil at 2250 ft.
5. The four prospective pools mentioned are close to tide water and good ports.

DISCUSSION

E. DeGolyer, New York, N. Y. (written discussion*).—Since the eastern part of the Gulf Coastal Plain is receiving considerable attention from various operators at the present time, it occurs to me that a brief review of most recent operations may be of interest in this connection, as well as a discussion of some of the points suggested by Mr. Hager.

During the latter part of January, 1918, the Alahoma Oil Co. completed and abandoned a 3400-ft. (1036-m.) dry hole in Section 25, Township 8 North, Range 1 West. This well was drilled near the axis of the

* Received Feb. 23, 1918.

Hatchetigbee Anticline, a short distance northwest of Salitpa and started in the Hatchetigbee beds, the equivalent of the upper Wilcox formation in this region.

The well was drilled with rotary tools. I am indebted to the courtesy of Mr. Landes of the Pennsylvania Oil Co. for a detailed copy of the driller's log. The log, in its present condition, cannot be correlated altogether with the geologic section, the only reported formation which can be recognized with any degree of certainty being some 950 ft. (289 m.) of hard, white, chalk rock which was passed through between depths of 1700 and 2650 ft. (518 and 807 m.). This formation is evidently the Selma chalk, including probably the Ripley, as suggested by Mr. Hopkins. The well was apparently drilling in the Tuscaloosa beds of the upper Cretaceous when abandoned.

The log reported gas at depths of 700 to 707 ft. (213 to 215 m.), 750 to 756 ft., a showing of oil and gas in the Selma chalk between the depths of 2120 and 2170 ft. (646 and 661 m.) and salt water in a white sand just below the Selma chalk at depths of 2650 to 2660 ft. There seems to be a general impression among those who watched the development that the oil show might have been of some importance in this well, and that it may be of considerable importance at other places on the anticline. It is doubtful whether it was of any great importance in the well in question, for though the well was not bailed dry when this show was encountered, the first attempt to drill a hole resulted in failure at a depth of some 2200 ft. (670 m.), while after the rig was moved a few feet, the well which was finally completed was drilled. The oil show was passed through by both wells.

It is of some interest geologically to note that the section from the Hatchetigbee beds to the Selma chalk is apparently somewhat thicker than as suggested by either Hopkins[1] or Hager. If one accepts the maximum thicknesses of the various formations from the Hatchetigbee to the Ripley as given by Hopkins, including both formations, he gets a total thickness of 1450 ft. (442 m.), and as given by Hager, he gets a thickness of 1195 ft. (364 m.). The well which evidently started below the top of the Hatchetigbee shows a thickness of 1700 ft. (578 m.) to the top of the hard white chalk, which probably not only includes the Selma in this area but also the Ripley, as noted by Hopkins.

The remainder of the log is kept in terms of gumbo, shale, shells, rock, etc., and presents nothing of particular interest except several comparatively thin beds of "black rock" which may be either lignites or carbonaceous shales.

At the present time, an important test is being drilled on the axis of

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[1] Oliver B. Hopkins: Oil and Gas Possibilities of the Hatchetigbee Anticline, Alabama. *U. S. Geological Survey Bulletin* 661-H (1917).

the anticline near the point where it crosses the Tombigbee River, by Messrs. Keoughan and Hurst. This well was reported on Feb. 14 as having a depth of 200 ft. (60 m.) and drilling. I believe it is the present plan to drill this well to a depth of about 1600 ft. (487 m.) with rotary tools and then complete a very deep test with cable tools. Such an operation should give a first rate test of the territory.

The Empire Gas and Fuel Co. is reported to have a rig up in the southwest quarter of Section 13, Township 9 North, Range 3 West. This well, which will be drilled with rotary tools also, lies near the axis of the anticline in its northwestern extension and at a distance of about 10 miles from the Keoughan and Hurst well just mentioned.

It is reported that Messrs. Boykin and Landes will drill a well on the Jackson anticline in Section 34, Township 6 North, Range 2 East.

Operation in this region is, of course, the veriest sort of wild-cat drilling and the odds against the successful outcome of such ventures are always large, but the local and regional geology are both very favorable and the structures are certainly worthy of a complete test. The general regional dip of the rocks is gently toward the Gulf, consequently there is a broad possible collection area; the sedimentary rocks include a number of beds porous enough to provide good reservoirs and beds impervious enough to form good cap rocks; water is present in quantities great enough to assist in the migration of oil and the local structures are entirely favorable to its accumulation.

Mr. Hager suggests that it is doubtful whether all of the area embraced in the folds would be productive (if we take for granted the presence of oil) and that cross folding, minor anticlines, etc., will probably control the accumulation. I am of the opinion that the major structures are sufficient to control the accumulation and that the actual deposits, if such occur, will probably be controlled more by the varying lithologic conditions of certain beds, especially their variations in porosity.

I would further suggest that the operations now being carried on and proposed should give the crest of the anticline a fairly good test and that further exploratory wells on the Hatchetigbee anticline particularly should be drilled on the south flank of the fold.

Certain theoretical considerations would seem to make exploration in in this part of the Coastal Plain very attractive. I believe that the theory is generally accepted that oil has originated in sedimentary rocks over fairly wide areas. Whatever the origin, oil is known to occur widely in a more or less disseminated condition in the sedimentary rocks and it is the secondary occurrences or accumulations of oil which are of commercial importance. Conditions of sedimentation have not varied so widely in the part of the Gulf Coastal Plain lying between the Mississippi River and Florida as to make it unlikely that the same oil-forming agencies have been operative in this sector as in the remainder of the perimeter of the

Gulf of Mexico. The factors controlling migration are apparently as favorable as they are at the other points around the perimeter where large oil deposits have been found. The sedimentary rocks dip generally Gulfward around its entire perimeter, and oil fields or considerable indications of oil have been found throughout most of its extent, including Cuba, Mexico, Texas, and Louisiana, except in the sector under discussion and in Florida.

It is of further interest to note that gas in small quantities has been encountered in wells drilled in the vicinity of Mobile. These wells start much higher stratigraphically than the Hatchetigbee formation, however, and are not believed to have reached that formation.

Mr. Hager has not mentioned the Lower Peach Tree structure which has been described at various times by Smith.[2] This structure consists of a fold faulted on the north side and of an extent almost equal to that of the Hatchetigbee Anticline. It lies more or less parallel to the Hatchetigbee fold and at a distance of some 25 miles (40 km.) northeast of it.

I. N. Knapp, Philadelphia, Pa. (written discussion*).—The *Niles National Register*, of Aug. 14, 1841, gives an account of finding oil in Alabama in an operation for the removal of the McGrew shoals on the Tombigbee River. This account says: "A quantity has been collected, and upon application of fire, it is found to burn equal to the present sperm oil."

Mr. Hager mentions gas and some oil as being found near Birmingham, Ala., in the Pennsylvanian beds. I think this mention should have also included the gas found in Fayette County (see *Bulletin* 10, *Geological Survey of Alabama*). Here several sands occur in the same series of rocks, containing gas in commercial quantity. Showings of oil are also found, enough to be seen on the drill stem and in the bailer, but not enough for a paying production.

"Fossil resin" is reported as occurring at the top of the Cretaceous or bottom of the Tertiary in numerous places, according to the geological survey of Alabama made in 1894 by Dr. Smith. As the analysis shows this substance to be very low in ash (0.15 per cent.) with about 60 per cent. volatile matter, and 40 per cent. fixed carbon, it seems to me this might possibly indicate an oil showing. I have visited Southern Alabama several times and searched for, and found, this "fossil resin," but found nothing that indicated an oil seep.

I have seen the Bladen (or Cullom) Springs well, all the old wells around Jackson, and the gas seeps of the old salt wells; also the gas well at Mobile, which originally gave over 100,000 cu. ft. of gas per day.

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[2] Eugene A. Smith: Concerning Oil and Gas in Alabama. *Geological Survey of Alabama, Circular No.* 3 (1917).

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Principles and Problems of Oil Prospecting in the Gulf Coast Country

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I. Introduction

(a) Extent of the Gulf Coastal Plain

The Gulf Coastal plain of the southern United States is that area bordering for a large part the Gulf of Mexico and extending inland and northward to the main interior highland region. It is more or less V-shaped and includes the States of Florida, extreme southern Alabama, all of Mississippi and Louisiana, the eastern and southern half of Arkansas, and the eastern, southeastern, and southern portions of Texas. While the contents of this paper apply to the Gulf Coastal plain in general, they are intended to refer more specifically to that portion of the plain included between the 90th and 97th meridians, and the 29th and 33d parallels, an area that may be described geographically as comprising western Mississippi, all of Louisiana, part of eastern and all of southeastern Texas. It is within this area that numerous and prolific oil pools have been developed during the last 17 years.

(b) History of the Important Gulf Coast Oil Pools

Oil in commercial quantities was first found in the Gulf States at Corsicana, Tex., when, in 1896, a well was drilled into a sand at 1030 ft. (313.9 m.) and came in at 22 bbl. daily production. Forty-seven wells followed quickly thereafter, so that in 1897 this small pool had a yearly production of 60,000 barrels.

Attention was first drawn to the Gulf Coastal region as a prolific source of petroleum, when, on Jan. 10, 1901, after several previous unsuccessful attempts by other operators, Captain A. F. Lucas brought in Lucas No. 1 at Spindletop, Tex., with an estimated initial flow of 40,000 to 75,000 bbl. daily, from a sand at 1120 to 1139 ft. (341 to 347 m.). Although the productive area of this pool covers only 250 acres (101 ha.), it has yielded approximately 45,000,000 bbl. of petroleum.[1]

The Lucas well was epochal in that it demonstrated beyond question the possibilities of the so-called salt domes as favorable reservoirs for the accumulation of oil. Although the value of the professional petroleum geologist in locating favorable drilling territory had not been recognized at that time, operators with a keen sense of judgment and practical turn of mind began an active investigation for salt domes. Several, which had been recognized for some time, were leased and an active drilling campaign instituted. Previous to the Lucas discovery, Savage Brothers attempted to develop the Sour Lake field, where several shallow wells were drilled in 1894–95. The results of these tests were not strongly encouraging. However, in 1901, after the successful test at Spindletop, J. M. Guffey *et al.*, who had financed the Lucas well, began an active development at Sour Lake, Tex., where a large spring showed considerable

[1] Statistics ontotal production complete to Jan. 1, 1917, only.

sulphur water and oil. Although the Guffey interests found a pocket of gas at 822 ft. (250 m.) and a good oil sand at 1400 ft., this dome did not obtain much prominence until 1902, when Sharp Brothers brought in a 10,000-bbl. gusher. Small tracts of land, 40 by 50 ft., near this well sold as high as $10,000 and derricks were built so close together that they often overlapped. Sour Lake, to date, has produced approximately 46,000,000 bbl. of oil and still has a daily output of 12,000 to 15,000 bbl.

About the time of the important developments at Sour Lake, interest was also being directed toward Jennings, La., the topography of this region being similar to that of Spindletop and gas having issued from the springs of the vicinity. The first well was drilled by the Heywood brothers for the Jennings Oil Co., and struck the pay sand at 1822 ft. (555 m.) in August, 1901. The well gushed oil and sand for several hours, but eventually clogged up. Jennings No. 2, brought in by Heywood brothers on June 28, 1902,[2] was the first satisfactory well in the field. In 1904, the Chicago-Jennings No. 2 gusher came in at 2000 bbl. Production from the deep 1900-ft. sand began in 1904. Bass & Benckenstein's No. 1 came in at about 14,000 bbl. per 24 hr. and the Heywood Oil Co. No. 1 yielded about 10,000 bbl. daily. A marked falling off in production was noted in 1905, when many of the big wells went on the pump. Gushers again brought the pool into prominence in 1906, the year of maximum production. Since then there has been a gradual decline. Jennings has yielded to date about 40,000,000 bbl. of oil, but at present has a daily production of only 2000 bbl.

The Saratoga dome just north of Sour Lake was next drilled, and came in a producer in 1902. Although credited with approximately 18,000,000 bbl. production to date, its present daily average is only about 2000 bbl.

In October, 1903, the Batson pool, just to the west of Saratoga and Sour Lake, was opened with a 4000-bbl. well. The following year this dome produced 11,000,000 bbl. of oil and has yielded a total of about 28,000,000 bbl. Its present production is about 2000 bbl. daily.

The famous Humble pool next attracted the attention of the oil fraternity. A shallow well was drilled in 1902, but terminated in a gas blowout. Some oil and gas was found between 1000 and 1200 ft. (304 and 365 m.). The real development at Humble dates from the drilling of a well by D. R. Beatty on Jan. 7, 1905, the D. R. Beatty No. 1, which had a gusher production of 10,000 bbl. daily. The Humble pool has proved to be one of the most prolific and long lived of any in the Gulf Coast region, and at present, 13 years after its discovery, gusher wells of 8000 to 10,000 bbl. daily production are brought in. Until the recent activity at Goose Creek, Humble held the front rank in daily production for the Gulf Coast country, and, to date, has produced approxi-

[2] G. D. Harris: Oil and Gas in Louisiana. *U. S. Geological Survey Bulletin* No. 429 (1910), 53.

mately 62,000,000 bbl. and has a present daily production of about 20,000 bbl.

Early in 1905, shortly after the developments at Humble, Savage and Morrecal attracted attention to North Louisiana by drilling in their Townsite No. 1, which proved to be the discovery well of the famous Caddo field. As soon as the value of the discovery was fully understood, a drilling campaign was inaugurated, resulting eventually in the extension of the field northward to Vivian and eastward to Houston, covering an area of 125 sq. miles (324 sq. km.). Caddo has ranked second only to Humble in the record of daily and total production, and the staying qualities of the wells. Since 1905, it has yielded 50,000,000 bbl. of oil and at present has a daily production of 16,000 to 18,000 bbl. Unlike the majority of pools in the Gulf Coast field, Caddo is not a salt dome structure.

The next pool to achieve prominence was located at Vinton, La. Oil had been pumped from water wells only 40 ft. (12 m.) deep in this region, and when Spindletop was discovered, attention was immediately turned toward Vinton. The initial attempts to develop a pool were unsuccessful, owing to the fact that this area did not possess shallow productive sands, as did many of the other domes, and hence no one drilled deep enough. Finally, in 1910, a 250-bbl. well was brought in at 2100 ft. (640 m.). An active drilling of the field followed, and for a short time it yielded 100,000 bbl. daily; wells making as much as 20,000 bbl. daily were drilled. This flush production was of a temporary nature only, however. Today the pool is averaging between 3000 and 4000 bbl. daily and has yielded a total production of about 9,000,000 bbl.

In 1913, activities to the south of the Caddo field resulted in the opening of the Naborton pool in DeSoto parish. Subsequently the territory around Crichton and in the vicinity of Red River was successfully developed, these areas being classed as the DeSoto-Red River field. In 1914, the Naborton pool yielded 3,800,000 bbl. of oil, and in 1915, the Red River field produced 6,800,000. To date, the DeSoto-Red River fields combined have yielded 19,000,000 bbl. of petroleum and are at present producing at the rate of 8000 to 12,000 bbl. daily.

The discovery well of the Edgerly pool in Louisiana was brought in in June, 1913, by the Bright Oil Co. Development of this area, however, did not really begin until 1914. During that year, Edgerly yielded 600,000 bbl. of crude and increased this to 1,400,000 bbl. in 1915. The pool is a small one, having yielded 3,250,000 bbl. of oil to date. It is now producing at the rate of 3500 to 4000 bbl. daily.

No further commercial developments of interest were recorded until August, 1916, when the erratic Goose Creek pool again commanded attention. The discovery well at Goose Creek was drilled in November, 1907, and was of the gusher type. Immediately thereafter two large

producing companies expended hundreds of thousands of dollars in developing the pool, without satisfactory results. The original well found the sand at 1600 to 1700 ft. (487 to 518 m.), but so small were the subsequent wells drilled into this pay, that the output during the last half of 1908 was only about 11,000 bbl. Here again the error lay in failure to drill deeper. The larger companies retired from Goose Creek about 1910, and the only development work done thereafter was by small companies and individuals. In August, 1916, Mitchell, Groesbeck, Prewett, and associates[3] in deepening an abandoned hole, struck a sand at 2200 ft. where the gas caused a blowout. The well ran wild for several days, spurting oil above the top of the derrick and over the immediate vicinity. The initial daily production of the well was estimated at 10,000 bbl. Finally this well sanded off and ceased flowing, but was eventually cleaned out. This is the origin of the present activity at Goose Creek which has placed it temporarily in the front rank of the Gulf Coast pools. Since then, leases have commanded enormous bonuses because numerous large gushers of from 3000 to 10,000 bbl. daily production have been drilled. No field in the Gulf Coast region presents a scene of greater activity than Goose Creek, which now boasts of a daily production of from 27,000 to 30,000 bbl.

The year 1917 has continued to add its quota of new pools discovered. Chief of these is the dome at Damon Mound. During May, the Texas Exploration Co. attracted attention to this locality when their Bryan No. 3 came in a gusher at 3000 to 4000 bbl. daily. In August, this company's Bryan No. 1 came in at 3470 ft. flowing 8000 to 10,000 bbl. daily, but shortly thereafter settled down to less than half this quantity. This dome is yet in the initial stage of development, but less than a half dozen wells have been yielding a daily production of 4000 to 5000 bbl. With continued development, there is promising indication that Damon Mound will soon take favorable rank from the standpoint of production with the other pools. At the end of September, 1917, nearly 500,000 bbl. of oil were stored in earthen reservoirs awaiting facilities to take it to market.

The second field discovered during 1917 is at New Iberia, La., where, on May 24, the Gulf Production Co. brought in Bernard No. 1 flowing at the rate of 1200 bbl. daily. This well has been pumping 110 bbl. a day. Very active development is in progress in this region, but so far the results have been somewhat disappointing.

(c) *Favorable Features of the Gulf Coast Pools*

From this brief résumé, it will be seen that, dating from 1901, great oil pools have been opened up in the Gulf Coast region with frequency

[3] The author is indebted to P. L. McCreal of Houston, Tex., for some of the historical notes on Goose Creek and several other pools.

and regularity. These pools have been characterized by prolific sands and gusher production. Moreover, many of the pools are favored with several productive sands, some of which are encountered at quite shallow depths. These features, combined with a rising market, a demand for petroleum which cannot be met with the present sources of supply, and the success of the professional geologist in locating favorable drilling territory, have been the cause, during the past three years, of the most scientific examination to which the Gulf Coast country has ever been subjected. Nearly all of the large operating companies have expended thousands of dollars in maintaining large corps of geologists to investigate this region. Some of this expenditure has returned satisfactory results; in other instances, the opposite has been true. The methods which the geologist has found so successful in Kansas, Oklahoma, Wyoming, or the Eastern States cannot be applied here. Moreover, most of the large companies have been forced to send into the Gulf Coast country geologists who are but slightly familiar with the special, specific, and difficult problems associated with coastal plain work. The present paper is devoted, therefore, to a statement and discussion of the elementary but fundamental principles on which successful geological investigations in this region are conducted, and to a presentation of some of its problems, with suggested methods of attack and solution.

II. General Topography and Physiography

The region immediately along and closely adjacent to the Gulf shore line is characterized by very low relief and broad river valleys. It may be better described as a very flat coastal prairie, broken occasionally by slight mounds whose summits are elevated 10 to 80 ft. (3 to 24 m.) above the level of the surrounding plains. These mounds are a typical topographic feature of the coastal salt domes.

Farther inland these coastal prairies merge into the hilly region of the Gulf Coastal plain. The latter covers a much larger area, is gently dissected by numerous streams and their tributaries, and is comparatively of much greater relief, being characterized by numerous small to fair-sized hills, 300 to 700 ft. (91 to 213 m.) in elevation, produced by the differential erosion of inclined sedimentary rocks.

Deussen[4] divides the eastern and southeastern coastal plain of Texas into the following physiographic units, named from the coast inland: (1) the coast prairie; (2) the Kisatchie wold; (3) the red lands, and (4) the Yegua timber belt, the two constituting the Nacogdoches wold; (5) the Corsicana *cuesta*. A wold is defined as a "range of hills produced by differential erosion from inclined sedimentary rocks." Many of these

[4] Alexander Deussen: Geology and Underground Waters of the Southeastern Part of the Texas Coastal Plain. *U. S. Geological Survey Water Supply Paper* No. 335 (1914), 15.

hills are capped by rock of considerably greater hardness than the underlying strata, which tends to accentuate their relief. Such hills partially deflect the streams crossing them, causing the latter to follow courses along the foot of the ranges for some distance. Locally, even in the hilly regions, the major streams have carved wide river valleys and in such valleys have formed alluvial plains of 1 to 10 miles in width. These Deussen more correctly designates as constructional plains, but they are more generally known as "bottom lands."

The greater portion of the Gulf Coastal plain is heavily timbered. Generally the type of timber seems to be influenced by the character of the formation. Along the bottom lands, hardwoods predominate and here will be found white and red oak, willow oak, white and green ash, pecan, shagbark, white hickory, sycamore, sweet gum, cottonwood, etc., whereas pine forests cover the sandy hills and divides.

III. General Stratigraphy of the Gulf Coastal Plain West of the 90th Meridian

Unconsolidated sands, sandy clays, clayey sands, shales, sandstones, clays, and gravels constitute the surface formations of the Gulf Coastal plain. These formations belong to the early and later Tertiary and Quaternary systems. The early Tertiary formations of Eocene age are separated from the underlying Cretaceous formations by an unconformity.

In describing the various formations west of the 90th meridian, the classification as proposed by Deussen is closely followed. Most of the formations found in Southeastern Texas are stratigraphically continuous eastward to the 90th meridian. Exceptions to this general statement, with the corresponding change in classification, are presented in Table 1.

Midway Formation.—This consists of very characteristic black, calcareous to gypsiferous clays and sandy shales often containing good-sized calcareous concretions, and fossiliferous limestones. In east Texas, bluish, micaceous clays and clayey sands compose the base of the formation, while in Mississippi, a hard, crystalline limestone known as the Clayton limestone is the lowest Midway unit succeeded by a series of calcareous sandy marls. The lower portion of the Midway is of marine origin, while the upper portion, especially in east Texas, is of palustrine character. The formation varies from 20 to 400 ft. (6 to 122 m.) in thickness.

Wilcox Formation.—In general, this is composed of loose, unconsolidated sands, clays, sandy clays, sandy shales, and lignites. Great lenses of yellow and red sands with some white sands seem to be a characteristic feature. The generalized section for east Texas from top to bottom consists of white, porous, loose, water-bearing sands—typically exposed at Queen City—lignitic beds, and lenticular masses of red and

TABLE 1.—CORRELATION OF GULF COAST FORMATION

System	Series	Arkansas-Louisiana Formation	East Texas Formation	Western Mississippi Formation
Quaternary	Recent	Fluviatile	Fluviatile	Fluviatile
	Pleistocene	Beaumont Clay	Beaumont Clay	Not differentiated
		Lissie Gravel, or Lafayette*	Lissie Gravel, or Lafayette	Not differentiated
		Unconformity	Unconformity	Unconformity
Tertiary	Pliocene and Miocene		Dewitt	Not differentiated
		Fleming Clay Unconformity	Fleming Clay Unconformity	? Unconformity
	Oligocene	Catahoula	Catahoula Sandstone	Catahoula Sandstone
		Vicksburg Limestone		Vicksburg Limestone
	Eocene	Jackson	Catahoula Sandstone	Jackson
			Jackson	
		Claiborne Group: Cockfield	Yegua	Cockfield
		Claiborne Group: St. Maurice	Cook Mountain	Lisbon
			Mt. Selman	Tallahatta Buhrstone
		Wilcox	Wilcox	Wilcox
		Midway	Midway	Midway
		Unconformity	Unconformity	Unconformity

* Geologists in the Gulf Coast region have preferred to designate as "Lafayette" that formation which Deussen has termed the "Lissie gravel." In a private communication to the author, William Kennedy has called attention to the fact that the Lafayette of eastern Texas and western Louisiana is typically and almost altogether a gravel, whereas the type section at Lissie reveals but a poor exposure of sand.

yellow sands and bluish white clays which occasionally contain crocodile teeth and large concretions of flinty sandstone 6 to 30 ft. in diameter and, finally, marine beds of glauconitic marls, often fossil-bearing, and alternating with layers of sand and clay. Cross-bedding is a most conspicuous feature. With the exception of the Queen City sands, practically the same succession obtains in the Louisiana exposures. The lignite beds are generally more conspicuous in Mississippi.

Owing to the palustrine conditions which were synchronous with the deposition of the Wilcox, the formation presents such extremely variable lithologic characteristics that it is difficult to identify positively any particular horizon. Deussen states that seaward the formation "grades into glauconitic and fossiliferous marls of marine origin." The Wilcox

is distinguished from the underlying Midway formation by the presence of well-defined beds of lignite, fossil leaves, the practical absence of limestone ledges, and the scarcity of marine fossils. It varies from 400 to 1000 ft. (121 to 304 m.) in thickness.

Mt. Selman Formation.—This is the lowest member of the Claiborne group in Texas and might be lithologically designated as the iron-ore formation, since a large part of it is made up of a hard, siliceous, limonitic to hematitic iron ore of somewhat concretionary character. Massive ledges, 5 to 20 ft. (1.5 to 6 m.) thick, of this ore are not of uncommon occurrence. A very red sandstone near the base of the Mt. Selman contains casts of *Venericardia planicosta.* Many of the red sandstones so characteristic of this formation are probably formed by the alteration of greensands. Cross-bedding of a pronounced character is indicative of the palustrine nature of the deposit, although occasional dark green and brown sands point to a possible marine phase also. The formation is 200 to 400 ft. (60 to 121 m.) thick.

The Tallahatta[5] *buhrstone,* the stratigraphic equivalent of the Mt. Selman in Mississippi, is composed of aluminous sandstone or siliceous claystones of marine origin. Beds of fossiliferous greensand are also present, weathering into the typical red beds which constitute such a conspicuous feature of the lower Claiborne. The Tallahatta buhrstone is 200 to 400 ft. thick.

Cook Mountain Formation.—This formation, of lower Claiborne age, outcropping conspicuously in eastern Texas, is described by Deussen[6] as follows:

> At the base of this formation occur beds of greensand, greensand marl, and iron ore, all highly fossiliferous and of marine origin; in the medial portion, lignites, lignitic clays, and sands of palustrine origin are found; at the top occurs another series of fossiliferous greensands, greensand marls, and iron ores of marine origin. Fossils characteristic of the formation are *Ostrea sellæformis Conrad, Ostrea divaricata Lea,* and *Anomia ephippiodes Gabb.* The estimated thickness of the formation is 400 ft. (121 m.).

The stratigraphic equivalent of the Cook Mountain formation in Mississippi is designated as the Lisbon formation. It is composed largely of lignitic clays and calcareous sands.

The St. Maurice formation, in Louisiana, is the stratigraphic equivalent of the Mt. Selman and Cook Mountain formations. The St. Maurice is distinguished from the underlying Wilcox chiefly in its tendency to more calcareous, glauconitic, and clayey phases, and the almost complete absence over the greater part of its area of ligniferous material. The St. Maurice is highly fossiliferous and the outcrops are more typically

[5] Bailey Willis: Index to the Stratigraphy of North America. *U. S. Geological Survey Professional Paper* No. 71 (1912), 735.

[6] *Ibid,* 727.

red in color, due to the weathering of the greensands. It varies from 300 to 700 ft. (91 to 213 m.) in thickness.

Yegua Formation.—This is a lithologic unit of the upper Claiborne, consisting of characteristic lignites with clays and sands of palustrine and marine origin. The palustrine features are dominant. The formation is from 375 to 750 ft. (114 to 228 m.) in thickness.

Cockfield Formation.—This is the equivalent of the Yegua formation in Louisiana and western Mississippi. It possesses the same physical and lithologic characteristics as the Wilcox, except for the almost complete absence of any marine mollusks. The Cockfield must be identified either by its stratigraphic position or on paleontological evidence. It is 300 to 400 ft. (91 to 121 m.) in thickness.

Jackson Formation.—This consists of a series of calcareous, fossiliferous clays of marine origin with large limestone concretions. In Texas, the Jackson passes westward into the Catahoula sandstone which here occupies a lower position in the geologic column. Eastward, in Mississippi, the Jackson is represented by gray sands and clays of a calcareous and lignitic nature. Still further eastward, the formation is of a limestone character. The Jackson is of marine origin and generally regularly stratified, a condition quite unusual in most of the Gulf coast formation. It is characterized by the fossils *Umbrella planulata Conrad, Levifusus branneri Harris, Trochocyatus lunulitiformis var. montgomeriensis Vaughn.* The outcrop in eastern Texas is of a narrow lenticular character which broadens in an easterly direction. It varies from 50 to 250 ft. (15 to 76 m.) in thickness.

Catahoula Sandstone.—In eastern Texas, the Oligocene is represented only by the Catahoula sandstone, which is excellently described by Deussen[7] as follows:

> The Catahoula sandstone lies stratigraphically and conformably above the Jackson formation in eastern Texas and above the Yegua in central and southwestern Texas. It is a lithologic and stratigraphic unit which transgresses several biologic zones. Stated differently, it is conceived to be of different ages, and to have been laid down at different periods in the different regions of its occurrence. It consists of a series of gray and blue sandstones, interbedded with brown, gray, and green clays, gray sands, and a few deposits of lignite. The sandstones in places carry marine fossils; in other places, they carry casts of palm leaves, reeds, and great quantities of silicified and opalized wood. A characteristic feature is the occurrence locally of very hard, blue quartzites, which, owing to their superior hardness, resist weathering better than the adjacent materials and appear topographically in the form of hills. These quartzites pass laterally in very short distances into soft, gray sandstones, and unconsolidated sands. The formation ranges in thickness from 500 to 800 ft.

Vicksburg Limestone.—In Louisiana, the lower Oligocene is represented by a very small area of Vicksburg limestone which broadens and develops

[7] Bailey Willis: *Op. cit.*, 729–730. Alexander Deussen: *Op. cit.*, 69–70.

into beds of considerable prominence in Mississippi. Here the Vicksburg attains a thickness of 65 to 75 ft. (19 to 23 m.) and consists of a series of hard, blue, semicrystalline limestone beds, 1 to 3 ft. (0.3 to 0.9 m.) in thickness, separated by beds of yellowish, sandy, fossiliferous marl. The limestone beds weather into a soft, yellowish phase. The Vicksburg is a marine formation, containing typical fossils such as *Orbitoides*, *Pectens*, etc.

Fleming Clay.—The Fleming clay is here classified as belonging to the Miocene series. It is found outcropping in eastern and southeastern Texas and Louisiana, where it appears typically as a greenish, grayish to bluish, calcareous clay with small limestone nodules. These clays are often quite sandy and thin beds of grayish sandstone are occasionally observed, but the characteristic gray sandstone and quartzitic layers of the Catahoula formation are absent. It weathers typically into a black, clayey to waxy soil. Veatch[8] describes a bed of bright red clay near the base of the formation. The Fleming clay is 200 to 500 ft. (60 to 152 m.) thick.

In Mississippi, the Miocene and Pliocene deposits have not been differentiated.

Dewitt Formation.—This formation outcrops only in southeastern Texas. Eastward and southward it passes into a marine Miocene which does not outcrop but is overlain by the Lissie gravel. Deussen[9] describes the Dewitt as consisting of "gray, loosely consolidated, highly calcareous sands and sandstones, cross-bedded in places; brown, pink, green, and green-brown mottled clays, and conglomerates made up of rounded fragments of clay. In southwestern Texas, the clays in places carry dendrites of manganese or nodules of lime showing manganese stains. The calcareous sandstones and sands commonly lie at the base of the formation, and the clays and conglomerates predominate at higher horizons. Soils derived from it are prevailingly black loams."

The Dewitt formation is composed largely of deposits of lacustrine and littoral origin, is lacking in marine fossils, although possessing a few land vertebrates, and has a thickness up to 1500 ft. (457 m.).

Lissie Gravel or Lafayette.—An unconformity separates the later Tertiary deposits of Miocene and Pliocene age from those belonging to the Quaternary system. The lowest Quaternary unit has been designated by Deussen[10] as the Lissie gravel and is of Pleistocene age. Deussen claims this gravel formation consists actually of two or three distinct units separated by unconformities, these units resulting from the erosion and redeposition of a portion or portions of the original gravel bed.

[8] Bailey Willis: *Op. cit.*, 730.

[9] Alexander Deussen: *Op. cit.*, 75.

[10] Alexander Deussen: *Op. cit.*, 78–79.

The Lissie gravel is believed to represent the coalescing alluvial fans which spread out at the mouths of the valleys of the streams which discharged into the sea during some parts of Pleistocene time, possibly the early and middle parts. In lithologic character, the Lissie gravel is variable. * * * In places it consists of gravels and conglomerates of granitic origin derived from rocks such as quartz, jasper, flint, limestone and greenstone; in other places, it consists of gravels and conglomerates of limestone origin; and in still others, it consists of mottled sands and silts containing ferruginous pebbles and concretions.

Vertebrate fossils of Pleistocene age have been found in these gravels. The formation varies from a few to 900 ft. (274 m.) in thickness.

Beaumont Clay.—This formation, not exceeding 800 ft. (243 m.) in thickness, rests conformably on the Lissie gravel and may be described as a blue to reddish, calcareous clay and silt with small limestone concretions. Numerous lenticular-shaped sand bodies and sandy clays occur throughout the formation. The blue clays carry the Pleistocene fossil, *Rangea cuneata.* Bedded logs are of common occurrence.

Recent Deposits.—These cover a small area and consist of materials (alluvium) laid down along stream valleys, over flood plains and bottom lands during the present geologic era. The type of the deposit depends on the source from whence it was derived and may vary from red to yellow sands, clays, sandy clays, silts, and, in some instances, to mollusk shells

Résumé.—Thus a brief résumé of the lithologic characteristics of the various stratigraphic units which make up the Gulf Coastal plain indicates that the deposits are largely of palustrine and littoral origin, are often loose, unconsolidated, highly cross-bedded, generally with indefinite bedding or stratification. Owing to their variable characteristics, they are often difficult to identify and especially after being modified by intense weathering processes.

IV. Structural Types and Their Characteristics

The structures found in the Gulf Coast region which offer favorable reservoirs for the accumulation of oil may be classed in a general way as follows:

1. Anticlines produced by folding, as the result of lateral thrust pressure.

2. Salt domes produced in all probability by uplift as the result of upward thrust pressure from below.

Applying this classification specifically to the known pools and structures which have been examined and about which there is little question, Table 2 shows that salt domes are by far the more common in occurrence.

TABLE 2.—*Distribution of Gulf Coast Pools*

*Anticlines by Folding	Salt Domes and Salines	
Caddo	Anderson or	Brook's Saline
DeSoto-Naborton	Palestine Dome	Brown's Saline
Red River	Anse La Butte	Butler
	Ayish Bayou	Cote Carline
	Barber's Hill	(Jefferson's Island)
	Batson	Cote Blanche
	Bayou Bouillon	Chicot
	Bayou Castor	Coal Bluff Saline
	Bear Creek	Cedar Bayou Saline
	Big Hill	Coochie Dome
	Big Salt Saline	Damon Mound
	Bistineau	Davis Hill
	Bluff Prairie	Dayton
	Goldonna	Negreet
	(Drake's Saline)	Petite Anse
	Goose Creek	(Avery's Island)
	Graham's Saline	Pine Prairie
	Grande Cote	Price's Saline
	(Week's Island)	Rambo Saline
	Grand Saline	Rayburn's Saline
	Hackberry Island	Sal del Rey
	High Island	Saratoga
	Hockley	Smiley Saline
	Hoskin's Mound	Sour Lake
	Humble	Spindletop
	Jennings	Stiver's Saline
	King's Saline	Steen's Saline
	Kiser's Mound	Sulphur
	Loma Blanca	Terry
	Brooks County	Vinton
	McKim's Saline	Welsh
	Many	White Point
	Markham	Winnfield
	Matagorda	

.* Corsicana and Powell have not been classed under anticlines, since the accumulation at these places is supposed to be due to the cementing of the oil-bearing sands.

The term "saline" has been used confusingly and erroneously. In some instances, well defined salt domes have been designated as salines, as witness Brook's Saline and Grand Saline; in other instances, salt-incrusted flats, salt marshes, prairies, etc., devoid of domal structure and proved by the drill to contain no rock-salt core, have been termed salines. The author has chosen to interpret a saline as a more or less flat to depression-like area, sometimes marshy, and of several acres extent, characterized by an incrustation, impregnation or efflorescence of saline matter or by the presence of brine springs or seepages which tend to destroy existing vegetation. Sometimes a small salt-water lake or pond may occupy the depression. Thus salt domes may contain and sometimes be characterized by salines, but a typical saline is not a salt dome.

(*a*) *Anticlinal Structure*

Considering the anticlines, they are found to be rather complex at times with the varied features which are generally associated with such structures. There are no pronounced and special characteristics by which they may be readily identified, as in the case of many salt domes; in fact, owing to the specific nature of the geologic formations, it is more difficult to locate and work out anticlinal structure in the Gulf Coast area than in most regions. If the surface formation is of a hard, resistant character, the presence of an anticline might be indicated by certain topographic features such as pronounced ridges, dissected by stream valleys. Occasionally the drainage, especially where it flows in all directions from some approximately central point, might suggest structure. More often, owing to the soft and non-resistant character of the surface formation, the anticlines will appear topographically as flat to slightly undulating, low-lying plains resembling bottom lands. In order to prove that such a topographic type represents anticlinal structure, the geologist is forced to resort to dip and strike data gathered after a most painstaking search for small, well-defined outcrops at the head of ravines, gullies, along railroad and wagon-road excavations, cuts, and other favorable places.

(*b*) *Structure of Salt Domes*

In describing the topographic and geologic features which characterize salt domes, it is first necessary to divide such structures into two groups:

1. Those situated on the coast prairie adjacent to the Gulf.

2. Those situated within the hilly or wold region, 200 to 350 miles (321 to 563 km.) inland from the Gulf shore line.

1. *Domes of the Coast Prairie.*—The salt domes along the coast prairie adjacent to the Gulf form the chief topographic feature of an otherwise level prairie floor, often appearing as smooth, oval to circular mounds rising 10 to 80 ft. (3 to 24 m.) above the surrounding area. These mounds are believed to result from the upward pressure exerted by the crystallization forces of large masses of rock salt found several hundred to several thousand feet directly beneath them. The height and area of these mounds seems to be related to two factors, the size of the salt core and its proximity to the surface. Where the salt mass is large and encountered at a depth of several hundred feet, well developed, prominent mounds often result. Damon's Mound in Brazoria County, Tex., is a dome-shaped hill 85 ft. (25 m.) high, which not only forms the most conspicuous topographic feature of that region but may be observed distinctly for a considerable distance. Likewise, when the combination of small, deep-seated salt cores is known to occur, their surface manifestation is often

very slight. This may account for the almost complete lack of domal topography at Welsh and Edgerly in Louisiana, and at Markham in Texas.

Owing to the solution and leaching activities of underground waters, great portions of these salt cores may often be dissolved away, leaving large cavities. The weight of the overlying formations becomes so great that caving and sinking ultimately follow. Thus many of these mounds may have a central depression occupied by a small lake, a marsh, or a saline. The salines are the result generally of salt springs or brines which have come from below and, quickly destroying all vegetation, form large

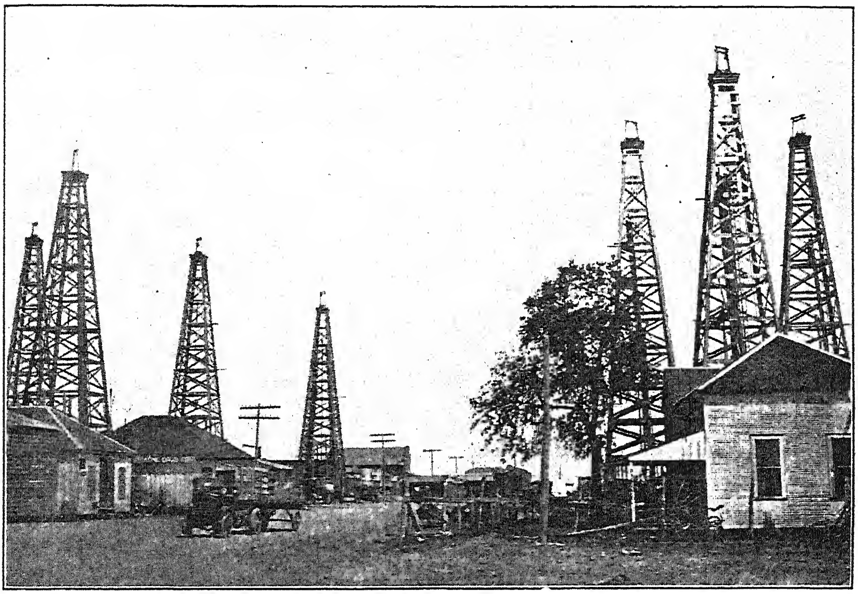


FIG. 1.—DEVELOPMENT AT DAMON MOUND, TEXAS.

saline flats, 5 to 30 acres (2 to 12 ha.) in extent. Such salines are observed at Anse La Butte, Louisiana, Sour Lake and Batson, Hardin County, Tex.; Davis Hill, Liberty County, Tex.; and in other regions.

Many of the mounds are featured by abrupt, comparatively steep slopes on one side with the opposite side long and gently inclining. Quite often the circular mound has been dissected by streams and the body of water which occupied the central depression has been drained. In some instances, erosion may have partly destroyed the mound, leaving a semicircular ridge bordered by a fresh-water lake or pond. In fact, stream action generally modifies the topography to such an extent that only portions of the original mounds remain. Such occurrences may be observed at Batson, Davis Hill, Goose Creek, Humble, Dayton, Hockley, and Kiser's Mound, Tex.

It is common to mistake wave ridges for these partly eroded mounds. The wave ridges have been formed by the action of waves along former shore lines and may now be observed miles inland. They are very long and narrow and are generally accompanied by parallel ridges, whereas an eroded salt mound is generally partly circular and not accompanied by parallel phases.

Gas seeps, asphalt seeps, crude oil in springs or wells, sulphur springs, mud volcanoes, black and white alkali flats covered with alkali grasses, and the presence of salty or brackish water in neighboring wells, are important geologic phenomena associated with the coast prairie salt domes. Of these, gas seeps are by far the most common; such seeps are found around the edges of marshes, along streams, ponds, in water holes and shallow wells. Very often such gas is confused with marsh gas, carbonic acid gas, sulphur gas, or just air bubbles, despite the fact that each possesses distinct characteristics and properties. Thus, seepages of gas which is associated with crude oil, emanating from the same or associated strata, bubble continuously; the bubbles are quite small, about the size of a 5- or 10-cent piece, and break quickly. A lighted match held close to them will cause sharp puffs due to sudden ignition. These seeps are not numerous. Only two or three, often some distance apart, may be associated with a dome structure, but at any time these seeps are inspected, the gas will always be found escaping from about the same place with little or no signs of diminishing volume.

Marsh gas, which is generally mistaken for gas associated with oil deposits, is formed by the decaying vegetation and organic matter in swamps or in the muds and slimes at the bottom of ponds. Marsh gas flows intermittently, seldom continuously. Very often it is necessary to disturb the bottom of the pond or marsh with a stick in order to start the flowing of bubbles. The bubbles are of various sizes, but usually larger than those formed by typical gas seeps, and the bubbles break more slowly. They will also ignite with a puff. Marsh-gas seeps are generally quite numerous in occurrence. When a considerable amount of such gas is present, bubbles will be found coming to the surface of the water first in one place and then in another at various parts of the pond or marsh.

Carbonic acid gas shows small, quick-breaking bubbles which extinguish a flame. Sulphur gas has an easily recognizable odor and will tarnish a silver coin. Air bubbles are never continuous, come to the surface of the water very slowly, are often quite large (about the size of a quarter or 50-cent piece) and slow-breaking. They never ignite.

Gas is often encountered in artesian wells, but too much weight should not be given to such occurrences because artesian water is gathered from a wide area and the gas which it may contain may have been gathered at some distance from where the artesian water is tapped and brought to the surface.

Asphalt appears as a black, hard to sticky, tar-like substance, light in weight, which melts and burns readily with a yellow, smoky flame and gives off an odor of oil. Investigation of the soil should always be made to ascertain whether the asphalt has come from a seep below, since there is a form of asphalt found along the Texas-Louisiana coast, sometimes termed "sea-wax," which has been thrown up in the form of small chunks by the waves. This asphaltic "sea-wax" may have been transported many miles from its original source and therefore does not indicate the local presence of oil.

Crude oil itself sometimes works its way in small quantities to the surface and is observed on the surface of ponds, lakes, streams, wells, and in springs. It is generally heavy, black, and greasy in appearance with brilliant rainbow hues where very thin films cover the water. It is often confused with iron oxide, which likewise produces brilliant hues on water surfaces. If a film of crude oil is disturbed by a stick, however, it strings out and tends to draw together shortly to form an unbroken surface, whereas a film of iron oxide breaks into flakes and does not tend to draw together for some time. Oil and asphalt seeps in the Gulf Coast region have been reported at Anse la Butte, Sulphur Mine, and Vinton in Louisiana; Spindletop, Sour Lake, Batson, Saratoga, and Hockley in Texas, but I have not been able to verify each occurrence.

Sulphur springs are one of the minor occurrences indicative of the possible presence of salt domes. They are the result of dissolved sulphur gases coming to the surface with the water and can be detected either by the odor, the taste, or the blackening of a silver coin. Several important pools have been developed in the Gulf region largely on the evidence of sulphur springs.

Other features characteristic of these domal structures are the presence of native sulphur, gypsum, or rock salt encountered in wells drilled for water or other purposes. Any new reports of such occurrences should be subject to investigation immediately.

2. *Salt Domes of the Wold Area.*—Salt domes of the hilly inland region of the Gulf Coastal plain may possess many features common to similar structures along the coast prairie. In addition, there are many special characteristics. In general, it may be stated that the inland domes of the wold area are much more difficult to recognize, owing to the fact that important topographic features associated with such structures are often obscured by the numerous surrounding hills and general topographic features of the entire region. Moreover, domes are found in the various stages of topographic development so that, technically, each dome presents features special to itself. Often a residual or transported mantle will obscure important characteristics so that the problem becomes sufficiently difficult to test the observation and ability of a well trained geologist, thoroughly experienced in coastal plain work.

Generally a salt dome within the wold region is surrounded or bordered by a circular range of hills which might be somewhat elliptical in plan. Such a range may be the result of somewhat harder beds which have been upturned during the process of dome formation, subsequently exposed, and subjected to erosion. Many soft clays and shales are associated with some of the harder beds. Due to the semitropical rainfall of the Gulf Coast climate, erosion is often deep and rapid. Thus the many resulting small streams will often cut through this circular range with such frequency as to render indefinite its true significance and relation to domal topography on casual observation. In this connection, it is important to suggest that the geologist obtain from some high elevation a bird's eye view of any area under examination where the general as well as the specific topographic features may be noted with their relation and bearing on structural possibilities.

In some instances, during an early stage of topographic development, the salt dome may possess a high central area represented by a group of hills covering ½ to 1 sq. mile (1.29 to 2.59 sq. km.) more or less; in other cases, the dome may contain a central depression occupied by a lake or marsh. Subsequently streams cutting back to this central depression will drain the lake, leaving a basin area. Salt licks and alkali marshes often form a part of these central depressions.[11]

A very conclusive feature often associated with salt domes is the exposure in these central depressions of unusual formations, formations not normal to the surface in that particular part of the country but generally encountered several hundred to 2000 ft. below. These formations are brought to the surface through the agency of the tremendous forces of upthrust with subsequent erosion and removal of the overlying strata. Faulting is often an accompaniment of such action. A typical example of such phenomena may be observed at the Anderson dome, 7 miles southwest of Palestine, Anderson County, Tex. This dome shows a circular range of hills surrounding a central depression which is occupied by a lake, ¼ to ⅜ mile in diameter. The surface formation here is the Wilcox of lower Eocene age, but around the rim of the lake may be observed the Midway of lower Eocene age underlaid by the Navarro formation, the Taylor marl, and the Austin chalk of upper Cretaceous age, strata which, normally, are encountered in this region several hundred to over 1000 ft. below the Wilcox, but which are now exposed at the surface because of upthrust and erosion. The Austin chalk is very conspicuous and readily identifiable, but sometimes these unusual formations can be recognized only by the peculiar soils into which they may weather. Hence if the geologist notes any unusual soil phases which differ materially from the general soil formed by the normal surface

[11] The author is indebted to L. C. Chapman for the use of some unpublished notes

formation, he should begin to suspect either faulting or upthrusting and erosion or both, and hence possible dome structure.

Any freakish condition revealed by a geologic examination should be investigated and its cause ascertained. Freakish conditions feature domal structures. A rock ridge crossing an area and not characteristic of the surface formation may constitute important evidence.

A typical, domal topography in the wold region will show a circular range of hills, deeply cut by stream erosion, surrounding a low, sunken and often flat area. These hills present sharp or abrupt inward flanks or escarpments facing the central depression radially whereas the outward sloping flanks of the hills away from the sunken area will be much more gentle. The beds of shale of which these hills are often composed will be found inclined downward and away from the central depression like the shingles on a house. The dip of these shales will be quite steep near the center of the dome but will show a gradually decreasing inclination as one passes from the center to the periphery. An unusually steep inclination of the strata, 20° to 40° should indicate at once to the geologist that he might be close to the center of a possible dome. Of course, it is necessary to make sure that the dip is on true bedding and not the result of false or cross-bedding so characteristic of many formations in the Gulf Coast area.

The drainage is another very important feature which should be studied, since drainage in the Gulf Coast country is often indicative of sub-surface structure. Drainage from a domed area may head on a water shed at some point near the center of the uplift from whence the streams radiate in all directions. If the drainage heads on a point to the side of the center, two main streams often develop which flow around each side of the dome and finally unite in a trunk stream. This is often an important characteristic. The distance between two such bounding streams may be 1 or 2 miles (1.6 or 3.2 km.) or, rarely, several miles. The circular valleys thus outlined are the result of erosion controlled largely by the dipping rocks and shales which are inclined away from the central portion of the uplift and shed the water outwardly.

The distance between the opposite flanks of a dome may be 1 or 2 miles, seldom greater. Generally no outcrops will be found in the eroded central depression which is often covered by a transported mantle. Outcrops will be found, however, on the flanks of the hills which have been described. It should be constantly borne in mind that salt domes are generally sharp, local structures of limited area. If elliptical in outline, the major axis may vary from ½ to 2½ or 3 miles in length with a minor axis of ¼ to 1 mile or possibly a little greater. Moreover, since the natural forces of erosion tend to reduce and modify prominent topographic expressions, salt domes in the hilly region will present varied periods of topographic development. Therefore, some of the features

characteristic of the domes in their earlier topographic history may become rather obscure in later stages. In fact, sometimes the only evidence indicative of possible domal structure consists of a few characteristic fossils of formations which have been brought to the surface by upthrusting and faulting with their lithologic characteristics entirely obliterated by weathering. Such fossil evidence should be left in place until its value is carefully ascertained, and then a proper record of the occurrence should be filed.

3. *Recapitulation of Dome Structural Characteristics.*—The following topographic and geologic features may be found associated with and characteristic of salt domes:

Salt Domes of the Coast Prairie

1. Often appear as oval to smooth, circular mounds, 10 to 80 ft. (3 to 24 m.) higher than the surrounding plains.
2. Central depressions occupied by a saline, salt marsh, or small lake.
3. Hills with an abrupt slope and opposite gently inclined flank.
4. Presence of gas, oil, asphalt seeps, and sulphur springs.
5. Presence of semicircular ridges bordered by fresh-water lakes.
6. Presence of mud volcanoes, black and white alkali flats, asphalt beds, brackish water wells, rock salt, gypsum, sulphur, etc.

Salt Domes of the Wold Region

1. Any of the features possessed by the salt domes along the coast prairie.
2. Generally bordered or surrounded by a circular range of hills which may be considerably dissected by cross-cutting streams.
3. In early stage of topographic development, may be represented by a group of hills forming a high central area.
4. Exposure at the surface of normally deep-lying formations due to upthrust, faulting, erosion, etc. This feature may also apply to the coast prairie domes.
5. Presence of unusual soils at the surface.
6. Freakish conditions such as presence of rock ridges in an area where there is a general lack of such features.
7. A circular group of hills, radiating from a central depression, with sharp, inward facing flanks or escarpments and gently outward sloping flanks.
8. Steep dip of the rock formations which gradually lessens in an outward direction from the center of the dome. This feature may apply also to domes along the coast prairie.
9. Certain conditions of drainage:

(a) Drainage in all directions from a central point.

(b) Two streams with their tributaries develop circular valleys and finally unite at one end of structure to form a main trunk stream.

10. Certain paleontologic evidence.

V. Methods of Surveying and Prospecting

In order to prospect the Gulf Coast country successfully, the features previously outlined must be thoroughly understood by the geologist. The methods of surveying which have recently been developed and applied

so advantageously in the Mid-Continental field will not be of much service in this region. For example, the plane-table cannot be employed with its usual efficiency, on account of the peculiar nature of the surface deposits, largely unconsolidated sands and gravels, soft clays, shales, etc., often cross-bedded and so varied in character that it is almost impossible to locate with sufficient definiteness any particular horizon extending over a sufficiently wide area. I know of only three localities in which a plane-table could be employed for mapping domal or anticlinal structure in the coastal plain: one was southeast of Bedias, Tex., where a well developed salt dome had numerous outcrops of massive, gray, Catahoula sandstone; the second was in San Augustine County, Tex., where a thin-bedded limestone outcropped consistently over considerable area; the third occurred in northern Louisiana where a bed containing sandstone and ironstone concretions in clay seemed fairly consistent. Many geologists have also tried to map structure with an aneroid barometer, but the results have been disappointing and unreliable, principally because relief of the district is generally insufficient to be recorded with sufficient accuracy in view of the well known limitations of barometric surveys.

The proper equipment for efficient mapping of coastal plain structure should include the following: Brunton compass; K. & E. stadia hand-level with Jacob's staff; 7-ft. stadia rod; register to record paces; notebook with leather belt case; small bricklayer's hammer with a flat chisel edge; a map of the area to be investigated. The stadia hand-level is almost indispensable. It can be readily mounted on a Jacob's staff and then employed as a fixed alidade, giving distances and percentage of dip quite accurately. For a stadia rod, a flat-sided stick, 7 ft. long, 2 in. wide, and ½ to ¾ in. thick, with alternate red and white divisions 1 ft. in length, is satisfactory and easily portable.

The question of maps is serious. There are six possible sources of supply: U. S. G. S. topographic maps; Dept. Agriculture soil survey maps; postal route maps; General Land Office maps; county survey maps; county road maps.

Of these, the topographic maps are by far the most satisfactory, but such a small area in Texas has been surveyed that these maps are seldom available. The soil survey maps are excellent, here also only a few small areas have been covered. The soil survey maps show all main, secondary, and private roads in much more detail than the topographic maps; they also show the drainage in detail. The postal route maps may be obtained for many districts; lack of details is their main drawback. General Land Office maps are usually unsatisfactory for this purpose, since they show only the land grants and surveys, omitting main roads, much of the drainage, and the railroads. It must be remembered that Texas has not been sectionized and nearly all the land surveys were made and

recorded in the old Spanish unit, the *vera*. Corner monuments have been totally obliterated in 90 per cent. of the cases and, in the absence of the topographic features, the Land Office maps are of little use. The ordinary county maps closely resemble the Land Office maps, often being a copy of the latter on a small scale. The county road maps offer some assistance, but are usually crude and out of date.

The survey is actually a detailed reconnaissance, wherein every highway, byway, and private road is traversed with a team and buggy, detours being made from any point along such roads where the country looks interesting or possibly favorable. Owing to the almost impassable

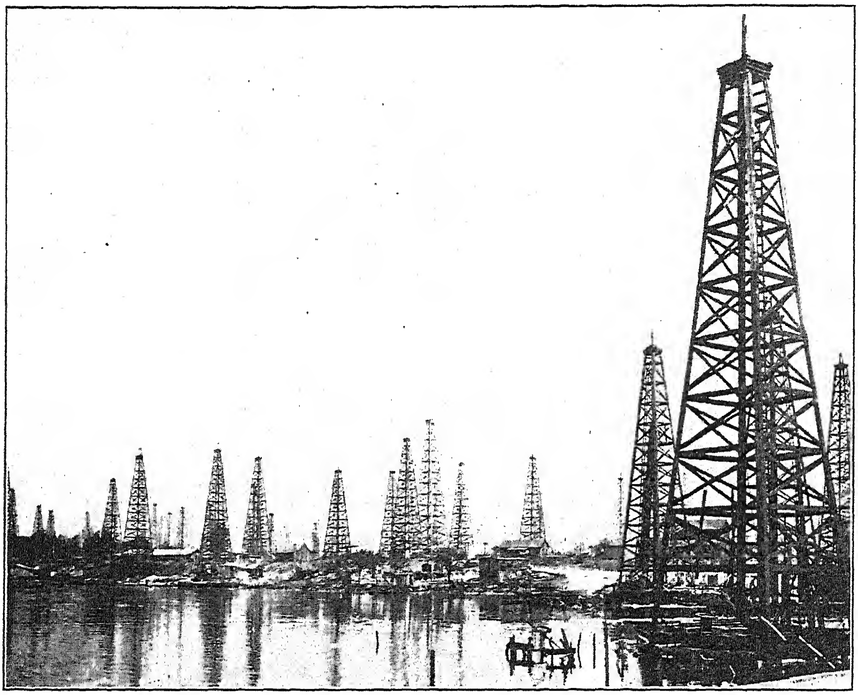


Fig. 2.—Bay front at Goose Creek, Texas.

character of some of the byways, it is impossible to cover the ground in a motor car. Heads of ravines, gullies, railroad cuts, wagon-road excavations, quarries, etc., should be investigated for outcrops of shale, sandy shale, sandstones and the like. At the heads of small gullies, the concentration of the runoff has generally cut sufficiently deep into the formation to expose fresh beds, the attitude and character of which has not been obliterated or made obscure by the deep and rapid weathering so characteristic of the region. It is almost useless to investigate main or well-developed stream beds, since weathering or transported materials have invariably almost eliminated any signs of outcrops showing true

bedding or stratification. Sometimes the exposure may be of sufficient length, or the same bed may outcrop in two or more places some distance apart along a ravine, so that the stadia hand-level can be used to take stadia readings on each outcrop. Knowing the distance and difference in elevation between them, the percentage of inclination of the strata can be easily computed.

When a favorable piece of structure is located, all dips and strikes should be connected by a Brunton compass traverse, which should then be tied in to the corners of the nearest land survey. After some experience with the Brunton and in pacing, a quite satisfactory map can be made by such methods. In all these investigations, a geologist is generally accompanied by an assistant who can either take the notes or work the register for recording the number of paces between stations. While making these traverses, important geological and topographic features can be easily located and mapped. The same applies to the geological formations.

While the main streams and well developed tributaries will almost invariably fail to show outcrops, they must be carefully inspected for possible seepages of oil and gas. When such geologic evidence is found, it should be located on the map and its relation to the structure determined.

The results of such a detailed reconnaissance as outlined depend a great deal on the ability, the initiative, the experience, and the conscientious attitude of the geologist toward his work. A man of sound judgment, who has spent several years in geological work, who possesses a keen observation and is exhaustive in his investigation, will achieve excellent results. Maps can be easily prepared which will not only define the possible limits of the structure but permit the making of favorable well locations. No map should be turned in until *every foot* of favorable territory has been covered. The fatal mistake of young geologists in this work is the tendency to cover the region too rapidly. They are under the impression that quantity is as important a factor as quality and if they do not turn out a certain amount of work within a specified time, they are not measuring up to the standard. Hence, many things are taken for granted and many points escape their observation. The slower but more careful and experienced investigator will cover just as much territory eventually, and in a much more satisfactory manner, since he will concentrate on favorable areas and speed up on unpromising regions. When thousands of dollars depend on the results of an investigation, the element of time becomes of minor importance. Generally, a very thorough report can be prepared on a favorable structure in 7 to 10 days, and a county of average size can be covered in detail in 2 to 4 months, the former estimate being nearer the average.

VI. The Development of Salt Domes

Salt domes are local structures of small areal extent as compared with the average anticlinal structures. It is a large dome that measures 2 miles (3.2 km.) in length and 1 to 1½ miles in width. Moreover, the sides of the dome are generally quite steeply inclined; therefore the possible productive area will be concentrated normally within a small radius from the apex and will not extend so far down the flanks as many producers seem inclined to believe. In developing a salt dome, the initial well should normally be located relatively close to the apex; if this well fails to strike gas or oil, the prospects are generally unfavorable for a second test. If it comes in a producer, development should then proceed carefully from the apex outward until edge wells or dry holes define the practical productive boundaries. Plotting careful log records will be of material aid in estimating and eventually defining such boundaries.

Dr. G. D. Harris,[12] one of the most experienced geologists in Gulf Coast work, discusses with such concrete definiteness and practicality the occurrence and migration of oil and gas in salt-dome structures, that his opinions are quoted directly as follows:

> The oil or gas may have collected in a concave-convex, porous crystalline limestone capping of the saline nucleus, as at Spindletop.
>
> Some oil may travel upward into pervious sands and there be held by overlying clays. The shallower "sands" at Spindletop and all the "sands" at Jennings are of this type. Again, the oil may be entrapped as it ascends in a porous stratum that has been tilted up and pinched out by the upward movement of the saline plug. Anse la Butte is an excellent example of this type of occurrence. In some places, the saline plug is not overlain by pervious or impervious layers [is truncated] and neither oil nor gas is now to be found near it. Grande Cote, Petite Anse, and Cote Carline are good examples of such barren domes.
>
> The sinking of a well into a salt nucleus whose upper termination is at or close to the surface of the ground * * * [will be generally unprofitable]. Such unsuccessful wells have been drilled at Goldonna, Anse la Butte, Petite Anse, Belle Isle, and other localities.
>
> If the saline nucleus in the upward movement has pierced, bent up, and turned aside pervious and impervious strata of whatever age, from Cretaceous to Quaternary, inclusive, that have never contained hydrocarbons in any form, the resultant domes cannot be expected to yield oil or gas. The large salt "islands" near the coast, and perhaps many of the saline domes in northern Louisiana and northeastern Texas, may prove to be of this type.
>
> If the salt nucleus, though approaching the surface centrally, has at depths of several hundred or even a thousand feet or more passed through pervious and impervious layers, some of which contain hydrocarbons, the chances are that the upbended margins of the pervious layers next to the rising salt nucleus will be so sealed or compressed as to produce local pockets wherein oil and gas may collect. Anse la Butte is an excellent example; Pine Prairie, Goldonna, Winnfield, and Coochie very likely fall into this category also. After a saline nucleus has been brought up near enough to

[12] G. D. Harris: Oil and Gas in Louisiana. *U. S. Geological Survey Bulletin* No. 429 (1910), 8–11.

the surface to be subjected to extensive underground flows of fresh water, more or less of the saline matter may be removed by solution, and accumulations of oil and gas may be set free and lost forever. Clearly the proper manner of testing such saline domes for oil and gas is not by wasting money in a deep salt hole centrally located but by searching for local pockets just outside the gas indications or circle of brine springs so common about these domes. Where the nucleus of a dome is volcanic matter, no one would think of drilling in the igneous mass. Then why should one drill in a salt nucleus? The supposed reason for the enterprise is not difficult to see. It rests wholly on a preconceived erroneous idea as to the origin and nature of the salt masses. They have been looked upon as kinks, sharp anticlines, or quaquaversals protruding upward from some widely extended salt sheet, and it is natural to suppose that under such structures oil and gas may be found. * * * The hope of obtaining a large supply of oil and gas by penetrating the Gulf Coast salt nuclei can, in the writer's opinion, never be realized. As already remarked, if the saline nucleus is many feet beneath the surface—say 1000 ft., as at Spindletop, or at an unknown greater depth, as at Jennings—and if between these depths and the surface there are pervious layers overlain by extensive impervious layers, the conditions are favorable for the collection of oil and gas, particularly at or near the apex of the dome, where they are obtained easily and in immense quantities. * * *. Generally the oil must be looked for immediately above the saline crystalline masses, or, where these are truncated at the surface, in the highly tilted peripheral layers.

Experience has demonstrated the truth and wisdom of the above deductions, although with some practical modifications. Thus a well which has been non-productive is generally abandoned when the salt nucleus is entered, for the reasons outlined above, but it is necessary to be sure that the main or parent salt nucleus has been penetrated. Very often several salt cores or masses of considerable dimensions may overlie the main salt nucleus at higher stratigraphic horizons. The piercing of these minor segregations, followed by deeper drilling, has often opened up prolific oil strata, showing that the main core had not been penetrated. Damon Mound, Goose Creek, and Sour Lake are notable examples. Often the main salt nucleus is so deep that penetration by the drill is impossible.

Companies which have small or no holdings in these regions, who wish to rush in and obtain adjoining acreage at once, with the bringing in of a good well in new territory, without waiting for a geological examination, are confronted with the problem of the price that they should pay. While each particular dome presents special problems which make it difficult and perhaps unwise to attempt to prescribe any definite rules, the following general procedure is based on study and experience, is conservative, and will save money in the long run. On a dome of average dimensions, say 1 mile by ½ to ¾ mile, and not exceeding 1½ by 1 mile, only acreage within ⅛ to ¼ mile of the domal apex is worth the risk of the high bonuses generally demanded; acreage within the area included between the ¼ and ½-mile circumferences should receive good average prices; acreage within the area included between the ½ and ¾-mile limits is generally risky and worth only a small bonus;

while acreage lying outside the mile limit is highly speculative and more often unproductive and worthless. The estimates thus outlined may be somewhat modified if the dome is decidedly elliptical in shape. If the apex of a dome of average size cannot be determined approximately by a hasty reconnaissance, and if reliance must be placed more or less on the position of the discovery well, which often is not located at the apex, it is advisable to modify the above defined limits by substracting $\frac{1}{16}$ mile from each fraction in applying this general rule of estimates.

A factor which must always be considered in connection with development is the possibility of the presence of faulting. Often such faulting is of a pronounced character with a throw of from one to several thousand feet, and the fault will often pass approximately through the center of the structure. In a few rare instances, the most productive area has been associated with such phenomena. More often such faults, especially if they have penetrated to the surface, have made possible the escape of all or part of the oil previously confined within the strata, or the escape of the more volatile constituents, leaving an asphaltic residuum. Where only part of the oil has escaped, the fault has probably been sealed by an asphaltic residue and has thus confined the remaining oil within its stratum. Generally, in the case of such faulting, the initial development well should not be located too close to the apex of the dome if such location would bring it adjacent to the fault. The best location under such conditions is several hundred feet away from and at right angles to the strike of the fault, taking into consideration also the dip and direction of the latter.

With the wild rush for acreage that generally occurs with the drilling in of a gusher well in the Gulf Coast country, it is often imperative to make quick decisions and immediate purchases but, nevertheless, the fact cannot be too strongly emphasized that a geological examination is almost essential as the foundation of any purchase involving large sums, and all the business acumen of the lease man should be concentrated toward securing an option from the land owner, if possible, or in conducting negotiations in such a manner so as to provide time for some kind of a geologic report.

The main principle to impress forcibly with respect to salt-dome development is that these structures are local in character, are in no way so extensive areally as the average typical anticline, and that commercial production normally will be confined within a relatively small area about the apex of the structure. On a typical anticline, acreage 2 to 5 miles (3.2 to 8 km.) from the discovery well might be exploited with success, but acreage 2 to 5 miles from the apex of a salt dome may be classed as worthless.

VII. Origin of Salt Domes

Many theories of origin have been advanced to explain the formation of salt domes. Some of these have been disproved with the subsequent development and more extensive study of the structures. At present, three theories have received scientific recognition:

1. Volcanic-plug theory of Hager.
2. Contemporaneous sedimentation theory of Norton.
3. Theory of upward pressure exerted by the force of growing crystals, as developed by Harris.

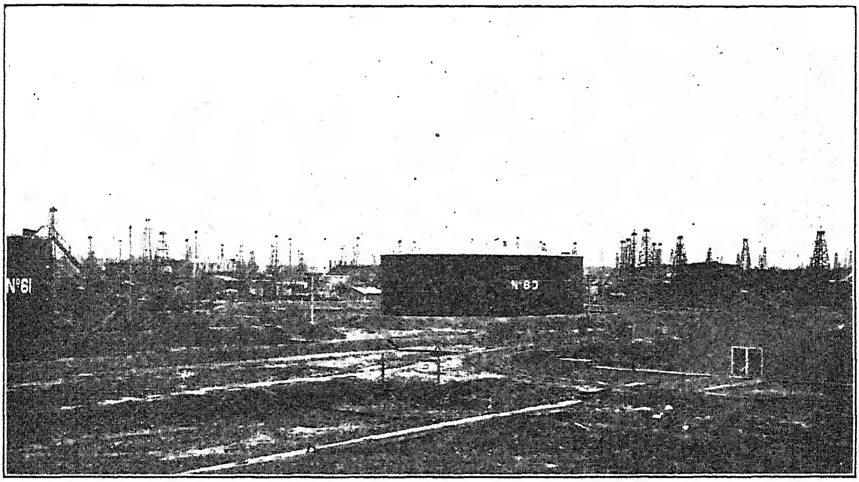


Fig. 3.—The Texas Company's plant, Humble, Texas.

Hager's Theory

Hager,[13] believes that the faulting of late Tertiary times in the Gulf Coast region was accompanied by deep-seated igneous activity.

Fault blocks resulted, thrust up by intrusive masses of igneous material in the form of laccoliths at great depth. Owing to the nature of the Tertiary deposits, yielding clays, marls, and quicksands, the faulting proper was confined to the deep-lying, indurated lower Cretaceous and Carboniferous rocks. In the unconsolidated materials of the overlying Tertiary and upper Cretaceous, dome-like structure resulted, due to the vertical thrust of the fault blocks pushed up by the intrusive masses in the form of laccoliths.

Heated waters from great depths found vent along the same channels, carrying in solution carbonates of lime and magnesium, gypsum, and salt. By ebullition and

[13] G. D. Harris: Rock Salt. *Louisiana Geological Survey Bulletin* No. 7 (1908), 71–72.

Lee Hager: The Mounds of the Southern Oil-Fields. *Engineering and Mining Journal* (1904), **78,** 182.

evaporation, these solutions became concentrated until saturation resulting, precipitation commenced forming the neck-like masses of salt, gypsum, and dolomite now encountered. A period of subsidence followed, during which the Coastal Quaternary beds were laid down, * * * followed by a secondary movement along the old lines of weakness, resulting in the present elevation of the mounds above the surrounding prairie.

It is possible that the fault lines may have furnished vent for the ascent of the petroleum from the deep-lying oil horizons of the Cretaceous and Carboniferous. * * * It seems probable, however, that the oil is indigenous to the Tertiary deposits, to some degree petroliferous in all horizons, and that the mounds but furnish dome-like structural conditions requisite for the accumulation and storage of oil

(b) *Norton's Theory*

Norton[14] also believes that the "salt deposits * * * were initiated by the intrusion of molten rocks into the underlying Paleozoic sediments along lines of structural weakness. These great faults were the sites of frequent downward displacements during the subsidence and deposition of the sands, clays, and littoral marine sediments of the Mississippi Embayment region."

Hot, ascending solutions, containing calcium and magnesium carbonates, sodium chloride, carbon dioxide, with varying amounts of hydrogen sulphide, mingled with the artesian saline waters of the Cretaceous beds. These waters were forced upward to the surface by the hydrostatic head of the region, through channels that were opened by the faulting and movement over these intrusions of igneous rock.

Great deposits of travertine or calcareous sinter, similar to the deposit at Winnfield, La., were formed around the thermal springs that issued from these openings. * * * As these great deposits of calcareous dolomitic sinters were built up, more or less gypsum was deposited in the surrounding marshes by the oxidation of the hydrogen sulphide coming in contact with the oxygenated surface waters, the H_2SO_4 so formed, converting the calcium carbonate of the spring waters into relatively insoluble sulphate.

Contemporaneously with the building of these sinters, sands and clays were deposited around their bases. * * * As the sinter continued to build, coincident with the subsidence and sedimentation of the region, the same excess of carbon dioxide in the ascending waters that prevented a deposition of carbonates in the channel below, attacked and re-dissolved the bottom layers. By the periodic rapid deposition of the sinter above and its slow, constant dissolution below by the carbonated saline waters, open spaces were developed that were carried upward in which the salt was deposited from ascending solutions that were supersaturated with saline contents by the release of pressure, as well as by the evaporative losses these waters must have sustained at the surface as the rapid sinter accumulation checked the flow from the springs.

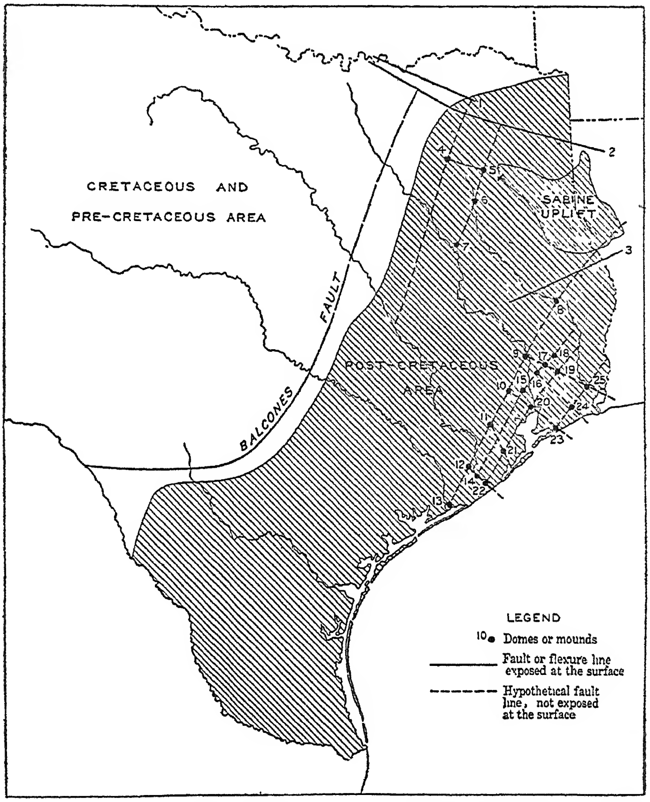
In this way, these salt deposits several thousand feet in thickness were built up contemporaneously with the sedimentation of the region and formed under their protective covers of sinter. * * *

The quaquaversal structural features of these domes are no doubt due to faulting and downward displacements.

[14] E. G. Norton: Origin of the Louisiana and East Texas Salines. *Trans.* (1916), **51**, 508-509, 511.

(c) *Harris' Theory*

In developing the theory of the forces of growing crystals and their bearing on the origin of salt domes, Harris[15] contends:



After Deussen, U S. G. S., *Water Supply Paper* No 335.

Fig. 4.—Principal structural features of the Texas Coastal Plain.

1. Red River fault.
2. Cooks Springs-Caddo fault and flexure.
3. Angelina-Caldwell monoclinal flexure.
4. Grand Saline Mound.
5. Steen Dome.
6. Brook's Dome.
7. Anderson Dome.
8. Graham's Saline.
9. Davis Hill.
10. Humble.
11. Blue Ridge.
12. Damon Mound.
13. Big Hill.
14. Kiser Mound.
15. Dayton.
16. Big Hill.
17. Batson.
18. Saratoga.
19. Sour Lake.
20. Barber's Hill.
21. Hoskins Mound.
22. Bryan Heights.
23. High Island.
24. Big Hill.
25. Spindletop.

1. That these salt masses are secondary in nature.
2. That water has been the dissolving and transporting agent.
3. That precipitation has resulted from a marked decrease in temperature of the saline solutions.

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[15] G. D. Harris: Rock Salt. *Louisiana Geological Survey Bulletin* No. 7 (1908), 75–79.

4. That the various salt domes show marked alignment even over great distances, which is the result of two great systems of faulting crossing nearly at right angles, the salt domes being located at their intersection.

5. That the quaquaversal structure of the domes has resulted from the upward forces exerted by the growing salt crystals due to the precipitation and crystallization of immense masses of rock salt from supersaturated solutions escaping along the fault lines of weakness and especially at the intersection of the two systems of faulting.

With respect to the faulting, Harris[16] states:

> This great delta-shaped area, bordered on the east and west by the Cretaceous-Tertiary contact line, and on the south by the Gulf, is characterized by northeast-southwest and northwest-southeast structural features. To suppose for an instant that the orderly rectilinear mode of occurrence of the saline domes is merely the work of chance is extreme folly. * * * Clearly, the varied wrenching and warping suffered by the rocks of this great delta region have given rise to structural features more or less parallel to the shores of the old Cretaceous terranes to the northeast and northwest. In the opinion of the writer, all the saline domes are located along lines of fracture in the deep-lying Mesozoic and Paleozoic rocks, and in general their location seems to be in the crossing of such lines.

It is beyond the scope of this paper to discuss exhaustively the merits and demerits of these various theories. The theories all agree with respect to three factors: that the salt masses are secondary in nature; that they have come from deep-seated solutions; and that these have ascended along faults or similar lines of weakness. Briefly, it may be stated that the main objection to Hager's theory is the complete lack of positive evidence to show the presence of volcanic plugs or laccoliths. Wells drilled over 4000 ft. (1219 m.) in depth have failed to encounter any indication of igneous material. Magnetic surveys on several domes have not produced the local variations in terrestrial magnetic forces such as the presence of a deep plutonic mass is almost sure to reveal, and it seems to be stretching the elements of probability and possibility too far to suppose or assume that the numerous saline domes are each underlain by laccoliths which show such remarkable rectilinear arrangement.

Norton's theory is ingenious in explaining the presence of the salt masses with a covering of crystalline limestone or sinter, but fails to account adequately for the most important fact—the quaquaversal structure. To attempt to account for such structure by "downward displacements" would not only introduce a series of complicated mechanics, generally contrary to nature, but is directly against the field evidence. Faulting and downward displacement might have pre-

[16] G. D. Harris: Oil and Gas in Louisiana. *U. S. Geological Survey Bulletin* No. 429 (1910), 9.

dominated in the early stages, due to loading of the embayment area, but the quaquaversal structure in its final phase must have been the result of great upward thrust pressure in order to account for the fact that formations which normally lie 1000 to 2000 ft. below the surface are now exposed either in contact with or partially overlying the normal and younger surface formations.

Harris' theory is by far the most complete, since it takes into account and conforms with all the most important and significant tectonic and geologic features characteristic of these dome structures. This theory is the only one which recognizes and explains the marked rectilinear arrangement of the salines. Norton[17] objects to the theory on the ground that the supposed faulting over wide areas as propounded by Harris to explain this rectilinear arrangement necessarily combines the elements of such great regularity over wide areas as to be contrary to probability, as manifested by nature's mechanics. This objection does not render the theory invalid, however, since it is quite possible for the general faulting to be more complex and still allow the major faulting to be along the lines suggested by Harris. Others have objected to the theory on the ground that examinations of many salt domes fail to reveal any evidence of faulting, but it must be borne in mind that the faulting may be very deep-seated, with surface evidence often lacking, due either to the elastic nature of the overlying Tertiary formations or their marked similarity in lithologic character, which, without definite paleontologic evidence, makes it almost impossible to discover and define these structural lines of weakness.

Recently laboratory experiments have been conducted under the supervision of Dr. Harris, which have demonstrated that the forces exerted by growing crystals, when applied on a scale comparable with the enormous salt masses under discussion, are more than sufficient to account for the upheavals which produced these quaquaversal structures. This theory is one of the most ingenious that has been propounded, conforms with the field evidence, is plausible, and has been generally accepted by geologists familiar with the Gulf coast region. It forms an excellent, reliable working hypothesis in conducting field operations.

VIII. Source of the Oil in the Gulf Coastal Pools

In northern Texas, Paleozoic sediments of Pennsylvanian age are prolifically oil-bearing at Electra, Petrolia, and Burkburnett. These sediments extend gulfward and there is no reason to presume that they have completely lost their petroliferous character within the region of the present shore line. The Woodbine formation of the overlying

[17] E. G. Norton: Origin of the Louisiana and East Texas Salines, *Trans.* (1916), **51**, 503.

Cretaceous beds is also highly oil-bearing, the Woodbine sand being the main productive horizon at Caddo, La. Numerous sand members of the Tertiary formations also possess a petroliferous character. With the gradual growth of the salt cores and the contemporaneous development of quaquaversal structure, artesian waters of these Pennsylvanian, Cretaceous, and Tertiary formations under great hydrostatic head undoubtedly exerted a great influence in the accumulation of oil in these dome-like reservoirs. In many instances, the crude petroleum has migrated from its original stratum upward until halted by overlying impervious clays and shales which obstructed its further passage. In

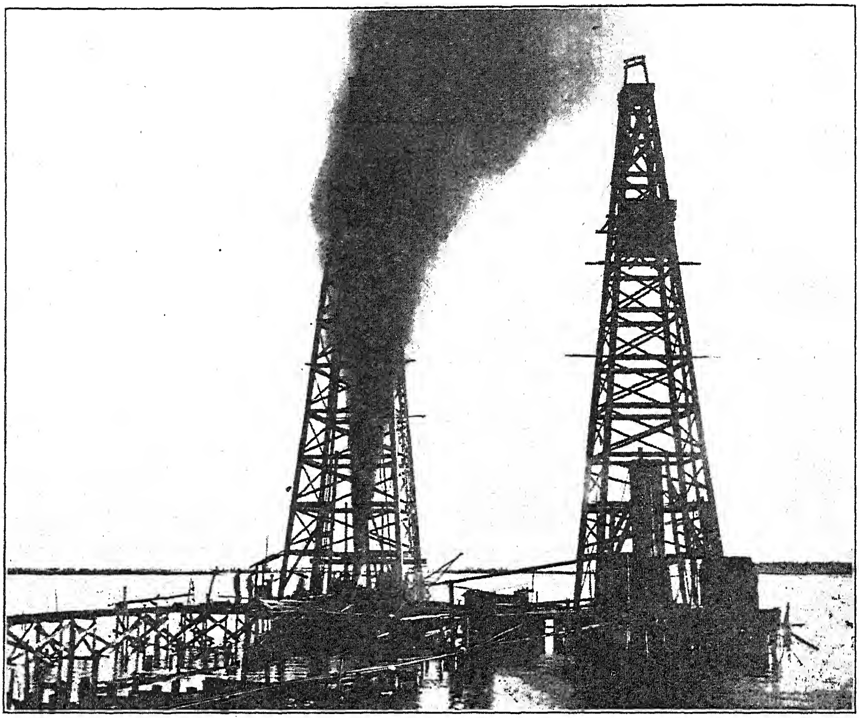

FIG. 5.—GUSHERS ON STATE LAND IN BAY, GOOSE CREEK, TEXAS.

some instances, where only lower Tertiary beds are present and are not overlain by impervious strata, the oil must come from underlying Cretaceous and Pennsylvanian formations. In other cases, the oil may have been derived entirely from Tertiary strata or from Pennsylvanian, Cretaceous, and Tertiary beds combined.

If the waters were to regress and uncover the present Gulf floor, salt domes carrying great quantities of petroleum would undoubtedly be discovered. At Goose Creek, Tex., development is now being undertaken in the bay, with successful results.

IX. Petrolific Value of Salt Domes of the Wold Region

It is most significant that, although numerous salt domes have been discovered and surveyed in the wold region, no structure to date has produced oil in commercial quantity in spite of the fact that extensive prospecting has been undertaken at several localities. One of the areas most recently tested is the Keechi dome, 7½ miles (12 km.) almost due north of Palestine, Tex., where the Producers Oil Co. has drilled four deep tests of from 2200 to 3000 ft. (670 to 914 m.) without obtaining satisfactory results. The first well encountered a very heavy asphaltic oil of pasty consistency, and rock salt at a greater depth. The heavy character of the oil might be due to the escape of the more volatile constituents, as a fault with a great throw passes almost through the center of the dome. The other wells have failed to encounter the oil.

Such discouraging results at this and other localities have raised the question: Have salt domes of the wold region commercial possibilities; will they ever become productive? Many geologists have answered this question in the negative, because of such results as have been outlined. I am inclined to a more optimistic view and believe the negative results are due either to an unfortunate choice of areas or to failure to study thoroughly certain conditions which, if understood in their fullest significance, would have condemned many areas before drilling commenced. It is useless to expect to find much oil in domes that have been truncated and where the main salt core is close to or exposed at the surface. Although big production has been obtained in close proximity to major faults, as at Humble, more often the opposite condition prevails. I am inclined to account for the absence of oil in commercial quantities at the Keechi dome on the basis of the presence of an enormous fault which bisects the structure. There seems to be no plausible reason why domes in the wold region, possessing favorable structural conditions—*i.e.*, deep-seated salt cores, no exposed faults of great throw, etc.—should not be commercially productive. The fact that such great quantities of oil have been found at Caddo should strengthen the belief that oil will be found in the dome structures west and southwest of that field if favorable structural conditions are discovered, since the oil-bearing sand at Caddo is known to extend over the region under discussion. In the future, large companies will be forced to undertake more prospecting and development in the wold region, and may uncover one or more prolific pools.

X. Future Outlook

Today Louisiana and Texas are producing more oil than at any other time in their history. Whether the peak of production has been reached is a question which the future only can answer. A great number of

undoubted salt domes and other structures presenting favorable conditions for the accumulation of oil and gas have been located, mapped, and leased. Some of these structures have been recently tested, with favorable results; others have proved unproductive. Many domes are now being developed, and the results will be awaited with interest. Others have never been tested or only in an uncertain and unsatisfactory manner. The present era of deep drilling not only has been wonderfully successful and gratifying but has changed the aspect of conditions. Domes which have been condemned because of the negative results of rather shallow drilling, now possess unexpected possibilities. While it is true that the majority of domes in the Gulf Coast field have possessed shallow sands which commanded attention before the deeper productive horizon was encountered, this condition has not always obtained. Whereas it had been more or less a general policy on the part of operators to abandon non-productive wells when any considerable quantity of rock salt was encountered, the discovery of commercially productive sands beneath such salt masses warrants the statement that territory is not necessarily condemned by unproductive wells drilled into salt at depths of 2000 ft. (609 m.) or less, unless there is strong evidence to indicate that the salt mass in question *is the main core.* Otherwise a well should be carried to greater depths, 3500 to 4000 ft. (1066 m.) before it is certainly classified as unproductive.

Although more geological investigation for oil has been undertaken in the Gulf Coast country during the past 4 years than in nearly all of the preceding years combined, there is much territory yet unprospected. Some of the work has been done very poorly, as a result of companies placing too much confidence in green college graduates. Hence some regions may be re-surveyed with profit. In connection with such geological investigations, it should be emphasized that one is not going to find in one or every instance all the profuse characteristics typifying dome structure, such as have been previously outlined. Several of the many features may be observed, however, and it becomes the function of the geologist to study these few features, estimate their relative importance, weigh the information obtained, and make his conclusions. The sum total of evidence presented by several features may be insufficient to warrant favorable action, whereas one pronounced characteristic may indicate beyond doubt the presence of a dome.

Companies should not be too conservative with respect to the quantity and quality of the evidence demanded before taking favorable action. While such a policy was to be commended a few years ago, conditions are now different. Today one sees many large and small concerns alike in strenuous competition for prospective territory, acreage is being taken miles in advance of actual development, and companies are carrying more acreage than ever before, much of which they have no

intention of drilling for years to come. The big corporations seem to believe that possibly crude oil production in the United States is at its maximum, that newly discovered pools are not eliminating the necessity of running storage oil from stocks to supply the market demand, and that new pools in the future are going to be fewer in number and much more difficult to discover. Acreage that was rejected 5 years ago as not giving sufficient surface indication to warrant development is now being purchased if it shows any favorable indications whatsoever. In other words, even greater chances must be taken in the future than in the past if the attempt to open up new pools and maintain present production is to be successful. With a mature understanding of this fact, the large corporations are adopting protective measures, with the result that the search for acreage is being carried on with an added intensity. The knowledge that condemned and rejected territory in the Gulf Coast region has turned out productive in several instances adds another phase to the problem.

Texas and Louisiana still offer excellent possibilities for oil prospecting and undoubtedly new pools will be added to those already proved. The fact that the most evident and easily recognizable structures have been located and either drilled or leased increases the difficulty of the problem, and should convince operators of the need and value of well-trained and experienced geologists to conduct the work of exploration. Realizing the import of these facts, one of the largest and most successful companies in the Mid-Continental field has diverted several millions toward the systematic investigation of the entire Gulf Coast country.

Besides Texas and Louisiana, Mississippi and southern Alabama should receive the attention of the petroleum geologist, since there is no plausible reason why domes and other favorable oil-bearing structures should be confined to the former States. Texas and Louisiana have always been designated as "the wildcatter's paradise" and will probably continue to be so despite the activities of the geologist, since all of the geologist's skill is of little avail if natural processes have eliminated or obscured all topographic and geologic evidence, as may sometimes be the case.

Acknowledgments

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DISCUSSION

A. F. Lucas, Washington, D. C. (written discussion*).—The writer notes with pleasure the detailed description given by Mr. Matteson

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in his efforts to solve the principles and problems of oil prospecting in the Gulf Coast country, which adds one more interesting paper to the innumerable articles already written on this subject.

While fully realizing that the more that the subject is described and discussed, the sooner we may arrive at the fundamental principles for research, and thus ultimately find the basic principle for determining the location of petroleum with more certainty and less waste of vast sums of money than by the methods now employed, yet, as the pioneer prospector and operator on the Coastal plain, and, in fact, the first to observe and attach special significance to the slight elevations on this plain which proved to be "domes" of vast economic importance in the development (1885–1902) of petroleum, sulphur, and salt, the writer feels it incumbent upon himself to correct some of Mr. Matteson's statements which might, if unchallenged, tend to produce a wrong impression of the facts as they exist. Such errors are easily accounted for now—even on the part of an observing geologist—when one considers that much that has been written on the subject of the Coastal plain (by experts and otherwise) too often contained inaccuracies and perversions of the facts as they existed, and also that during the lapse of years, keen activities of development, and the phenomena of nature render it difficult to visualize original conditions. A geologist, under the best conditions, has little opportunity for the use of instruments, and here where there are no ravines, gullies, or deep exposures, such as generally admit of study in a hilly country, the problem is a difficult one.

The writer found it so in 1896 to 1901, when he made a study of the economic possibilities of the Coastal plain. He searched in vain State and National libraries for bulletins or papers that might be of assistance to him in his investigations, but without result. Not possessing the education of a professional geologist or chemist, he had to adopt *per force* the senses with which nature had provided him, to wit, the use of hands, eyes and nose. To cite an instance, the analysis of a gas escape at Spindletop was obtained by inserting the neck of a clear glass bottle in a vent through which gas was seeping, with the result that in a few days a light film of sulphur formed on the glass, suggesting that the gas was H_2S. Again following the olfactory member, at High Island, Tex. (another great dome situated right on the coast of the Bolivar peninsular some 30 miles east of Galveston), he searched in vain, although satisfied of the existence of H_2S on the southern slope of the dome. Here his friend, Geo. E. Smith, who had leased him 1100 acres of the dome in December, 1900, brought him the lacking evidence in February, 1901, in the shape of an almost solid core of sulphur. Mr. Smith had great faith in medicinal or "sour" waters, such as are observed at Sour Lake and Spindletop, and had drilled some 8 years previously—with a post auger—holes varying from 5 to 10 ft. deep. Years later, when plowing, the plow encountered

one of these old holes (which had been plugged with sage grass) extracting therefrom a core of almost solid sulphur 6 in. in diameter and about 18 in. long. Obtaining this fact within a month after the advent of his great well, the writer realized the geological significance, that perhaps High Island might develop another dome equal to Spindletop that would have an area of 4000 acres instead of Spindletop's productive area of only about 275 acres.

These incidents are related here to emphasize the "hit or miss" indications that a geologist is subjected to in such territory. In addition, one is fairly bewildered by the imposing array of papers that have been published since 1901 by Federal, State, and private sources; in fact, by every ambitious farmer owning land in suspected territory, who straightway poses as a full-fledged geologist. While some publications serve a good purpose, there are many that merely bewilder one with their advance theories concerning problems and principles, in fact, one is almost blinded by the excess of light thrown on the subject.

With Mr. Matteson's kind permission, the writer must say that he could not have been correctly informed as to the early development on the Coastal plain. For instance, the Lucas No. 1 well was drilled in 1900 on the apex of the hill at Spindletop and was only 575 ft. deep. This well was lost, but not before the existence of an oil sand at its bottom had been ascertained, and two demijohns of a heavy viscous oil having a specific gravity of 17° B. had been obtained.

This was the *first* oil produced on Spindletop. The Lucas No. 2 well was drilled on the slope of the elevation and proved to be the great well,[1] estimated by some 30 Standard Oil officials and experts (while the well was still beyond control) to be delivering between 75,000 and 100,000 bbl. daily. (In my paper[2] written hurriedly for the Richmond meeting, February, 1901, I gave the lower figure, but its flow has never been put to a test.) That my theory as to the "dome" formation underlying Spindletop was correct, was borne out by subsequent investigations proving the limitations of the field to the area of the top of the dome, or as Marius R. Campbell so neatly expresses it, "showed that oil was practically limited to the dome and small mound which constituted its topographical expression."

The statement that oil and asphalt seeps have been observed at Anse La Butte, Sulphur Mines, Winton, La., and at Spindletop, Sour Lake,

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[1] The original producing oil well (Lucas No. 2) here referred to, was locally known as the Lucas Gusher, as it ran wild for some days before it was possible to cap it, the upward gushing column of oil being visible from a considerable distance and making a striking ocular vindication of the writer's theory that some salt domes contained oil, and that in such domes would be found oil in the Coastal plains.

[2] *Trans.* (1901), **31**, 362.

Batson, Saratoga, and Hokley, Tex., is assuredly erroneous, as no oil or asphalt seeps were ever observed by the writer or any of his men at Spindletop.

In contrast to the great number of geologists now employed on the Coastal Plain, in 1899–1901 none were detailed to Spindletop although it was then the only field undergoing exploration on the Coastal Plain. In August, 1900, Charles Willard Hayes, the Chief Geologist of the U. S. Geological Survey, and in March, 1900, Call Paine, formerly oil expert of the Standard Oil Co., both made flying visits, and to both of them the writer endeavored to justify his efforts to prove his theory of sulphur or oil accumulations under domes (then locally known as mounds or hills) on the Coastal Plain. Both gentlemen, however, took absolutely contrary views: the former stating that there were absolutely no precedents on which to base such expectations, and the latter quoting his world wide experience, during which he had never seen a deposit analogous to Spindletop. The results achieved by the discovery well establish, therefore, a precedent in original work.

Messrs. Looney, Savage Bros., and Sharp Bros. drilled on Spindletop some years before the writer but *without obtaining the slightest trace* of oil. The sulphur mines in Louisiana were drilled originally for oil during the Civil War but found, instead, a great sulphur dome with some viscous oil which produced from ½ to 1½ bbl. under the pump. About 1880 at Sour Lake, a company was organized by Galveston and New Orleans people which obtained a small production and built a small refinery, but, owing to the heavy viscous nature of the oil, it finally ceased operation. The writer is well acquainted with the location of these wells and this refinery, and has noticed hardened oil on the ground, an occurrence that may have been the reason for Mr. Matteson's mistake in ascribing an oil and asphalt exudation to this locality.

No sign of oil or asphalt was ever noted by the writer at High Island, Damon Mound, Big Hill, and Bryan Heights, where he had the honor to drill the first well on each of these locations for his company, the J. M. Guffey Petroleum Co. (now the Gulf Refining Co.). He was actuated by the same indices to drill on these domes in 1901 that led him to drill at Spindletop. Thus at Bryan Heights he established the existence of a great sulphur deposit (which is now exploited by the Freeport Sulphur Co.), at Damon Mound, found oil and sulphur, and at Big Hill encountered a solid bed of dolomite and salt rock; while at High Island, his first well, drilled in 1901 to 2175 ft., remains still today an unsolved problem, regardless of the fact that numerous wells have been drilled there since without results. However, he hopes that by "a lucky strike" or by further perseverance, High Island may obtain at least the result that Damon Mound did after its period of inactivity. Previous to the writer's

oil and sulphur discoveries, he had the honor to locate a great salt deposit at Jefferson Island, at Weeks Island and at Belle Isle, La.[3]

In reference to the eulogy of Dr. G. D. Harris' works, by Mr. Matteson, Dr. Harris is neither fair nor correct in his writings and plainly shows a disposition to minimize the efforts of development made by the writer. It would have been easy for Mr. Matteson to obtain correct data in the first instance, whether historical or technical, but in quoting from Dr. Harris he has not done this; on the contrary, he assumes certain biased issues incomprehensible to the writer, tending to discredit the development made by the latter. Reference is made to his statement in U. S. Geological Survey *Bulletin* 429, page 35, in which Dr. Harris says: "During the same year, 1899, Capt. A. F. Lucas attempted to drill an oil well in spite of poor tools and meager financial support. He soon left for Texas." Then he continues "The finding of oil at Spindletop early in 1901 called for new activities at Anse La Butte, etc."

He does not state, however, that in the first well at Anse La Butte, and regardless of poor tools, etc., the writer established the fact of the existence thereon of a salt dome, and sufficient oil to warrant renewed activity in 1901 not only by himsef, but by the J. M. Guffey Petroleum Co. (now the Gulf Refining Co.), Haywood Bros., and later Moresi Bros., and others, which brought this field into the limelight as a producer. Nor does he mention that when oil was discovered at Spindletop, the writer was the discoverer.

Dr. Harris also printed a statement in *Science*, Apr. 5, 1912, in which he advanced the theory of oil concentration about salt domes as his own, despite the fact that the writer had already established the theory by sufficient facts, not by surmises or writings, but by economic results; thus compelling the writer to deny the assertion, which he did in *Science* of the issue of June 21, 1912, but to which denial it will be noted Dr. Harris has as yet found no time to answer, and state on what foundation he based his claim.

The writer may, therefore, be pardoned for correcting the record, in view of the hardships and even ridicule incurred at the time at which he expounded his theory, which at that time was regarded as impossible but has since been proven conclusively to be eminently successful, and is now being followed and improved upon theoretically if one pleases to call it that, with innumerable variations, attributes, and geological theories.

Mr. Matteson further says that the proper method for testing such saline domes for oil and gas is not by wasting money on a deep salt hole centrally located, but by searching for local pockets "just outside the

[3] See A. F. Lucas: Rock Salt in Louisiana. *Trans.* (1899), **29**, 462; A Review of the Exploration at Belle Isle, Louisiana. *Trans.* (1917), **57**, 1034.

indicated circle of brine springs so common about these domes . . . When the nucleus of a dome is volcanic matter, no one would think of drilling in igneous mass . . . The hope of obtaining a large supply of oil, by penetrating the nuclei, can never be realized . . . The piercing of minor segregations followed by deeper drilling, has often opened up prolific oil strata, showing that the main core has not been penetrated, Damon Mound, Goose Creek, and Sour Lake are notable examples. Often the main salt nucleus is so deep that penetration by the drill is impossible."

Firstly, saline springs are *not* found generally, and are, in fact, observed only around the old Cretaceous domes in north Louisiana—Bistinau, Negreet, King, Price, Drake, Rayburn etc.—and no saline springs are anywhere noted on or around the salt domes of the Coastal plain prairie country, which is the subject matter of this paper.

Secondly, the nucleus of these domes is not volcanic matter, but of sedimentary formation.

Mr. Matteson's opinion is, of course, his own, and the writer knows that by differing with it he is in a measure disturbing a hornet's nest, as great diversity of opinion exists among geologists, yet nevertheless he begs to say that he differs entirely with that opinion, and he wishes to be placed on record within the course of his life, and afterward, as saying that the time will come when this opinion of Mr. Matteson will be in the main reversed. The writer does not desire at this time to give his reasons for this opinion, which will be the subject of another paper, but simply to go on record to that effect.

Mr. Matteson quotes three theories of origin, but he leaves out others equally important if not more so. The writer is in accord with Lee Hager and Eugene Coste, who advocate the volcanic origin of natural gas and petroleum.[4] The writer advanced the theory of oil accumulations by pressure or injection in laccolithic spaces either in the salt mass or in the cleavage of the salt floor which caused strata to bulge up, but without eruption at the surface. While in search of information on the subject many years ago, he asked G. K. Gilbert, one of the originators of the laccolithic theory, if it could be made to apply to a salt mass. Mr. Gilbert said that he could talk only in reference to plutonic rocks, and that he was not well acquainted with the sedimentary.

The writer hopes, therefore, that this subject will not only be studied, and discussed, but that attempts will be made to put it into practice, in selected localities, under the guidance of a reliable geologist, mining and mechanical engineer, as the subject is too important to be relegated to the background by timid theorists.

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[4] Eugene Coste: Volcanic Origin of Natural Gas and Petroleum. *Journal of the Canadian Mining Institute* (1903), 6, 73.

The country's needs for petroleum are growing, as production is decreasing, and the Coastal plain offers admirable opportunities to warrant combining a group of opulent oil interests, and the attempting of some necessarily hazardous tests in preference to the many costly shallow wells that are often entirely unproductive.

The Chairman (A. F. Lucas, Washington, D. C.).—Mr. Matteson has stated that the drilling of certain deep wells has proved a failure because they were abandoned too soon. He advises drilling more wells around salt domes, in the hope of finding additional oil sands.

I have had some experience on the domes and believe that by drilling shallow wells one loses time and money. I have advanced the opinion that by drilling central wells in the most likely location of a dome, showing a certain weakness, a better result could be obtained. I have in mind one locality where Mr. Knapp drilled a well through the salt—the only location that I know of on the Gulf Coast where oil was found underneath the salt. Mr. Knapp found a great deal of gas in it The salt itself was impregnated with oil and gas; and my opinion is that in such instances, instead of drilling so many wells around a dome, if you will attack at a weak point to as great a depth as a drill will go, the results will be much better. At present we have instances where drills have penetrated to 7300 or 7400 ft. in depth. Why couldn't the rich companies that are operating around the Gulf Coast arrange to get some special drilling apparatus and drill with the rotary first for, say, 3000 to 4000 ft., always in the likely location, and then proceed with the cable? I think we need just such work.

In Mr. Matteson's paper he quotes from an author whose writings, published in the U. S. and Louisiana Geological Surveys and elsewhere, have been quite extensive. He states that oil and asphalt have originally been found on the surface of those domes. I have been over and examined nearly all of those domes (not all of them, because many have been developed in the last few years) and found no such occurrence at the time; and in the old well-known humps or big hills, as they generally called them, I have never found either salines or asphalt or petroleum. In only one instance it looked as though asphalt might have exuded out of the ground, and that was in the Sour Lake, but right in that neighborhood years previous to that a company had operated commercially—they had a little refinery there—and had found it so unprofitable that they pulled up stakes and quit, leaving heavy oil on the surface, which has hardened since.

Upon the location that Mr. Harris and Mr. Matteson took, they might have thought that there were exudations of petroleum and of oil, which ultimately hardened up; but for the sake of history I want to emphasize the fact that I, as perhaps the first one who has studied

those domes with great care and success, have never been actuated to do so either by the oil or by the asphalt showing on the surface, because there was none.

There are also some inaccuracies about the saline statement. The salines that Mr. Harris has referred to, in Northern Louisiana, are in Cretaceous and are old and well known in Louisiana. Salines in the coastal plain may exist, but I haven't found them. I admit the lakes adjoining the domes, but they are generally of fresh water.

A very interesting condition exists there. I thought at one time, after my success at Spindletop, that if Spindletop furnished as much oil as it did in less than 300 acres, what would High Island furnish with more than 5000 acres? I thought I had the thing down fine, and naturally was ready to part with my interests at Spindletop, because I thought I had the great field of High Island in my pocket, but on High Island I drilled one 2200-ft. well that very year and got no economic result, and many wells have subsequently been drilled, with no success. High Island is, I think, about 49 ft. above the marshes; there are gas emanations there but I did not find the gas in considerable quantities.

Therefore, what we want is close study, but also deep wells, because there is little opportunity for studying the surface in those localities. As Mr. Matteson says, there is very little to see. In my opinion, the best way to study the domes is to drill some central wells at great depth and endeavor to ascertain the physical character of these domes in the hope of reaching some economic results. Owing to the fact that oil production within the next year or two will be growing less, I believe that some of those companies should take advantage of the opportunity to organize in some way, so that they will be prepared to drill real test wells, for, in my opinion, rather than drill half a dozen wells that cost all the way from \$5000 to \$20,000 each, 2000 ft. deep, why not drill one well 5000 to 7000 ft. to find out what we have under those domes and what they may suggest?

G. Sherburne Rogers,* Washington, D. C. (written discussion†).—Mr. Matteson's paper will doubtless be welcome to those who are suddenly called upon to undertake geologic work in the Gulf Coast country. The contribution is a timely one, for as the work of outlining structures in the Mid-Continent fields approaches completion, numbers of geologists will probably be released to prosecute the search for oil on the Gulf Coast, and these men will find themselves confronted by a very different and much more obscure problem. We are all so gratified by the marked

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* Associate Geologist, U. S. Geological Survey.

† Published by permission of the Director, U. S. Geological Survey.

success of geology in locating Oklahoma oil pools that we are a bit prone to forget that this success is founded upon sound principles concerning the relation of oil and structure, which were formulated many years ago, and the application of which in the field has become more or less mechanical. In the Gulf Coast fields, however, we know only that the oil is generally associated with salt domes; we have no well-defined methods for discovering buried domes, nor do we know why some are productive and others barren, or why oil is found on one side of the dome and not on the other. In other words, a vast amount of data has accumulated to substantiate Capt. Lucas' original theory of the occurrence of oil on salt domes, but we have made little real progress in extending this theory or in applying it in the field. Practically all of the producing fields were indicated to the discoverers by domal topography or by gas seeps; specialized geology has so far been of notoriously little practical value in advance of drilling.

In discussing the "proper equipment for efficient mapping of Coastal Plain structure "Mr. Matteson points out that the "plane-table cannot be employed with its usual efficiency" and recommends the use of half a dozen other surveying instruments, including a stadia hand level for "measuring distances and percentage of dip." All of these instruments will at least be useful for mapping culture and topography. They would also be valuable for mapping structure, if only structure could be found, but except in the northern or interior domes (which have so far proved unproductive) there seems little opportunity for thus using them. The most prolific domes are those having a surface elevation of only a few feet, and the slight deformation of the Pleistocene mantle is usually impossible to detect.

If structural methods are of little or no assistance, we must, as Capt. Lucas puts it, fall back upon "the senses with which nature has provided us, to wit, the use of hands, eyes, and nose." Domal topography and surface indications of oil or gas have so far proved to be the most reliable guides. Mr. Matteson adequately describes the characteristics of domal topography and warns against confusing wave ridges with domes. He might well have added a word of caution in regard to the "gas mounds," some of which have been drilled on supposition that they were salt domes. They are smaller than the true domes; the principal type in the oil regions generally, if not always, has a sandy core, and is usually found where the surface material is a clay underlain by sand. Their origin has long been disputed, but many geologists now regard them as formed by upward gas pressure, or simple hydraulic pressure, from the water-logged sandy stratum below. This would cause a slight doming of the thin clayey mantle, with subsequent puncturing, release of pressure, and discharge of sand, somewhat as the "sand-blows" associated with earth-

quakes are formed by the more violent ebullition of sand incident to the sudden earth strains.

Many true salt domes, however, have little or no topographic reflection and can scarcely be recognized on a 1-ft. contour map, but apparently there is always some kind of surface indication of the presence of oil. In addition to the oil and gas seeps, asphalt deposits, sulphur or salt springs, and mud volcanoes listed by Mr. Matteson, a very important and widespread indicator is the so-called paraffin dirt. This is a yellow waxy substance found filling the cracks in clay around the bare spots at which petroleum gas issues from the ground. It imparts a kind of resiliency to the soil, which springs beneath the step like rubber. Although paraffin earth has been analyzed repeatedly its exact nature is still obscure. Its significance as an indication of petroleum gas was recognized only a few years ago, but since that time its presence has been noted in nearly all the Gulf Coast fields. It does not necessarily indicate a salt dome, for it is reported at many localities in Louisiana and Texas north of the salt dome belt, and I have also observed it at Motembo, Cuba, where petroleum gas issues from soil overlying igneous rock.

Two somewhat different methods for the discovery of salt domes have been suggested. Shaw's[5] suggestion that the difference in specific gravity between salt and ordinary Coastal Plain sediments may cause gravity anomalies large enough to be detected, is certainly worthy of consideration and trial. The other method is based simply on the fact that salt domes are surrounded by a kind of *halo* of salt water—the ground-water directly above a dome may be as salty at a depth of 500 ft. as the ground-water a mile away at 2500 ft. A systematic study of the waters may establish a relation between the character of the water and the presence of oil, such as I have described in the California fields;[6] but even if no such relation can be discovered the high salinity of the water near salt domes may in itself prove a useful indication.

I cannot help feeling, however, that methods for the discovery of new domes are needed less urgently than methods for detecting the presence of oil on domes already known. The fact that one or two or a dozen dry holes have been drilled on a dome means little; a number of wells were drilled on Damon Mound between 1901 and 1917, when oil in commercial quantities was first found. Goose Creek was thought to be exhausted in 1915, but persistent prospecting finally led to the discovery of deeper sands and the field is now the second largest on the coast. At Damon the discovery was apparently retarded chiefly by the irregular

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[5] E. W. Shaw: Possibility of Using Gravity Anomalies in the Search for Salt-dome Oil and Gas Pools. *Science*, new ser., **46**, No. 1197, 553–556.

[6] G. S. Rogers: Chemical Relations of the Oil-field Waters in San Joaquin Valley, California. *U. S. Geological Survey Bulletin* No. 653 (1917).

and local distribution of the oil, but at Goose Greek it was primarily due to the fact that the wells, like all others on the coast, were drilled by the rotary method, and rich sands were entirely missed. The possibilities of few of the known domes have really been exhausted, and despite the great amount of drilling already done we know little of the precise factors governing the accumulation of the oil. In some fields oil has been found only in the shallow sands above the cap rock; in others chiefly in the cap rock itself; in others only in the deep sands that lie at steep angles around the flank of the dome; and in still other fields it is found under all three conditions. At Humble the oil in the deep sands or shales is found only on the eastern half of the dome, and we have only theories to explain its absence on the west side. I feel that these are problems of prime importance, and that it behooves us to solve them if possible before undertaking expensive surveys to discover new domes.

In view of the foregoing facts, Mr. Matteson's attempt to establish certain zones surrounding the apex of a dome and to place a relative value on them for leasing purposes seems futile and even dangerous. It is not clear just what he means by "apex," for the domes are characteristically flat-topped. The flat-lying cap rock at Humble, for example, underlies an area some 9000 ft. in diameter, and that at Damon Mound is but slightly smaller. At Goose Creek, Saratoga, and Edgerly, where the oil is derived from sands overlying the salt dome (if, indeed, a salt dome is present at depths yet unexplored), the beds are practically flat and the structural apex can be discovered only after a careful study of scores of well logs. If by apex Mr. Matteson means the topographic summit of the mound, his evaluation of the zones surrounding it is still open to criticism. Several domes, such as Stratton Ridge, Blue Ridge, Pierce Junction, and South Dayton, are not circular mounds but rather ridges so elongated that the position of the apex has little or no significance. Similarly at Saratoga, Goose Creek, Edgerly, Markham, etc., the topography bears no apparent relation to the productive area.

Another factor which tends to destroy the value of Mr. Matteson's estimates (and a factor which he unfortunately does not discuss in his paper) is the presence of productive deep sands around the flank of the salt mass itself, or lower than the cap rock. Such sands contribute the great bulk of the large production of Humble, the whole of the production of Damon Mound, and an important percentage of the production of several other domes. At Humble the belt of phenomenally rich sands begins from 1⅛ to 1¾ miles away from the center of the cap rock area and is about ½ mile broad; it therefore lies in the zone which Mr. Matteson characterizes as "highly speculative and more often unproductive and worthless." At Damon Mound, commercial production is at present limited to a small area lying about a mile from the summit of the mound and therefore also in the "highly speculative" belt. In several

other domes the cap rock area has been adequately tested and proved worthless, but there is good reason to suppose that production will be obtained from the deep sands on the flanks, ¾ mile or so away from the summit of the mound.

Mr. Matteson discusses theories of the origin of the domes and states that three "have received scientific recognition; the volcanic plug theory of Hager, the contemporaneous sedimentation theory of Norton, and the theory of upward pressure exerted by the force of growing crystals, as developed by Harris." It is unfortunate that he does not see fit to include the plastic intrusion theory developed by European geologists to explain the origin of the European salt domes and recently suggested by Van der Gracht[7] for the domes of the Gulf Coast. Briefly, this theory postulates the presence, at depth, of a bedded salt deposit, which, under the influence of great pressure and moderate temperature, becomes plastic and rises along lines of weakness, much as molten igneous rock rises to form a plug or a laccolith. This hypothesis is widely accepted in Europe and has much to recommend it—at least it seems entitled to "scientific recognition."

All of the theories yet proposed for the origin of salt domes unfortunately have one or more rather weak points. As Mr. Matteson points out, Norton's theory fails to explain the quaquaversal structure of the domes, and Hager's theory is weakened by the lack of evidence of the presence of igneous rock. I may note that this difficulty has, however, been somewhat palliated by the discovery, during the past summer, of volcanic ash in the sediments around one or two of the domes; of a rock resembling a porphyry in a well at Damon Mound; and of an undoubted igneous plug about 50 miles north of the salt-dome belt. Harris' theory, which has been the most popular and widely accepted, postulates the ascent of the salt to the surface in solution and its precipitation there through decrease in temperature. The weakness of this theory lies in the fact that 100 parts of water at 100° C. can carry 39 parts of sodium chloride, and at 20° C. about 36 parts, thus losing less than 9 per cent. of its total salt content under this drop in temperature. For every ton of salt precipitated, 10 tons must therefore have escaped in solution, presumably over the surface and into the sea. How such a saturated solution could reach the sea without further precipitation, due to evaporative losses, and the consequent formation of smaller bedded deposits of salt, is difficult to see, yet no salt or salt water is found in the Gulf Coast sediments to a considerable depth except around salt domes and along the Gulf Coast. Furthermore, the quantity of salt postulated by this theory is stupendous. A rough calculation of the amount of salt in the Humble

[7] Van der Gracht, W. A. I. M. van Waterschoot: The Saline Domes of Northwestern Europe. *Bulletin No. 1 of the Southwestern Institute of Petroleum Geologists* (1917), 85.

dome, assuming that the salt extends only as deep as it has actually been penetrated, gives a minimum figure of 66 billion tons. This represents all the salt in about 410 cu. miles of sea water or in 38 cu. miles of a saturated solution at 30° C. As this represents, according to Harris' theory, less than 9 per cent. of the salt involved, then over 650 billion tons of salt, forming about 400 cu. miles of solution, must have passed through the fissure and escaped. When we consider that Humble is simply one of several scores of domes, each of which would involve the movement and escape of a similar quantity of fluid and of salt, Harris' theory seems rather violent; and unless a precipitating agent more effective than decrease in temperature can be suggested the theory is in my opinion untenable.

The figures I have given constitute an argument against another theory as well, namely, that the salt is derived from the sea water which was entrapped in the Coastal Plain sediments when they were laid down and that it has been gathered into domes by concretionary action. If we assume that one-third of the Gulf Coast sediments are composed of material coarse enough to allow an appreciable movement of water, and that this material has a porosity of 30 per cent., we arrive at an average figure of 10 per cent. porosity, which seems liberal. The 66 billion tons of salt actually in sight in Humble represents about 410 cu. miles of sea water, which would therefore saturate 4100 cu. miles of sediment. When it is considered that the amount of salt in the Humble dome is certainly greater, and probably much greater, than 66 billion tons, and that this salt must, according to the theory, have been concentrated from the connate waters within about a mile of the surface (for the waters below that depth are still salty and could have contributed little), it appears that each dome must have drawn from a pretty large area, and that where the domes occur thickly these "spheres of influence" would be likely to overlap.

I fear that my discussion of Mr. Matteson's paper may seem rather destructive, for I have attacked several generalizations and have offered none in their place. His apparent object in writing, however, was to describe the characteristics of salt domes, and to outline methods for locating them, and I have simply attempted to point out that the difficulties attending the process of locating new ones may be due to the fact that we do not yet understand the nature and characteristics of domes discovered 20 years ago.

E. W. Shaw,* Washington, D. C.—One point concerning Van der Gracht's notion, should, I think, be borne in mind. Apparently the sediments which are supposed to have forced the salt upward are as

* Geologist, U. S. Geological Survey.

light or lighter than the salt,[8] and hence could scarcely have forced it upward by reason of their superior specific gravity.

Concerning the terms Lissie and Lafayette the point was made, I believe, that "Lissie gravel" is inappropriate because at the type locality there is no gravel and the name "Lafayette gravel" was urged as much more satisfactory. It may, however, be remarked that at the type locality of "the Lafayette" also there is practically no gravel. Moreover, it is doubtful if there is even a formation of any constitution, the so-called "Lafayette" being only the weathered portion of underlying formations.

As to the date of introduction of the name "Lafayette" I believe that Professor Hilgard is said to have used it in his notebooks previous to 1860, but the term did not appear in the literature and did not become current until McGee's classic monograph appeared in the Twelfth Annual Report of the Director of the United States Geological Survey in 1892. Between these two dates the materials received much attention, however, the most common name applied being "Orange sand."

Eugene Coste,* Calgary, Alta.—I would like to emphasize the remarks of our chairman in regard to deeper drilling under the salt domes, which observation might, of course, be extended in practically every other field, both oil and gas. I am glad to notice that Mr. Rogers also emphasized this point about drilling deeper. There is no doubt at all that the future of the oil and gas business is in deeper drilling, because the origin of the oil is from below. Those who do not understand that fact lack the faith that is necessary to carry out the principle to its natural conclusions, and therefore the origin of the oil is again shown to be the basic principal fact at the bottom of the whole industry, and of its future, in opening up new fields. This will especially be forced upon us in the next 10 years or so, when oil is going to become scarcer and scarcer. There will not be so many new States in which to open up new fields, as there have been in the last 15 years. We are now getting oil from Texas, Louisiana, Oklahoma, Ohio, Kansas, Indiana, Illinois, California, and Wyoming, besides the old producing States of Pennsylvania, New York, West Virginia, and Kentucky.

The question then, if we wish to increase production, which we shall have to do, is whether it is probable that additional oil can be found at greater depth?

The solfataric volcanic origin of oil, which I have supported for many years, indicates that it can. And not only that, but the history of the

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[8] E. W. Shaw: The Possibility of Using Gravity Anomalies in Finding Salt-dome Oil Fields, *Science*, Dec. 7, 1917.

* President and Chief Engineer, Canadian Western Natural Gas, Light & Power Co., Ltd.

fields also points to the same conclusion, that by drilling deeper in practically every field much greater production has been obtained.

For instance, along the Appalachian fields, we have 50 or 75 producing sands in a thickness of 10,000 to 12,000 ft. of strata, from the sub-Carboniferous sandstones adjoining the Pittsburg sandstone, down to the Potsdam sandstone of the Cambrian, showing that the horizon matters very little; whether the producing sand belongs to a certain formation or not is immaterial. Of course, oil and gas fields have also been found in the porous sands of many other formations, as in the Tertiary and Cretaceous, and in other formations. Especially is this the case in the salt-dome fields of Texas and Louisiana, where drilling at greater depth is certainly going to yield great benefits; and I am glad Captain Lucas, who is the pioneer in these fields, is of the same opinion.

Certain theories of origin have been mentioned; Mr. Hager's volcanic-rock origin, Mr. Norton's, Mr. Harris', and certain others. For the last 15 or 20 years I have suggested a solfataric volcanic origin. Mr. Hager thinks that the salt domes are due to the upthrust of volcanic cores, but he, as I understand it, attributes the origin of the oil under the domes to organic matter in the sediments, as other geologists, who believe in the organic origin, do.

I go much farther than that—I not only believe in the volcanic rocks under these domes, but believe that the salt, the sulphur, and the hydrocarbon emanations are also absolute, direct emanations from below. Structure is only a small thing in the geology of oil—it is only the shape of the vessel containing it. Sands are also only a small thing in the same connection—they are only the containers, the tanks, the vessels containing the oil, and whether they are Cambrian, Silurian, Carboniferous, Cretaceous, or Tertiary tanks is all the same, so long as they have been filled with the hydrocarbons from below.

If one could understand that oil and gas are found along tectonic lines, in petroliferous provinces analogous to metalliferous provinces, because in both cases the origin (of the petroleum as well as of the metals) is from deep magmas, then one would have faith in drilling deeper and in going nearer the source of these emanations.

That this would bring great results in such fields as the salt-dome district is evidenced by the enormous quantities of oil that are found in Mexico today. In the same coastal prairie, in Mexico, we find volcanic cores sticking hundreds of feet right out of the sediments, and along these volcanic cores are the great oil fields of Mexico. It is a short distance from Mexico to Texas, and the same phenomena are found there in the salt domes, only the cores are deeper.

It is perfectly evident to me, when I examine all the evidence of this oil phenomena in Louisiana and Texas, and in Mexico, that we have exactly the same thing, except that in Mexico the volcanic cores are evi-

dent, while in the other cases they are still buried. The hydrocarbon emanations, however, have come up alongside of these volcanic cores in both places, although not so obviously in Texas and Louisiana as in Mexico.

Considering that the Spindletop Mound has produced over 50,000,000 bbl. of oil out of 120 to 150 acres, it is absurd to suppose that this is due to the fact that it is a dome and that it is an accumulation of oil under that dome from the domed sediments; the volume of sediments under those 120 and 150 acres which have been domed would not be nearly sufficient to account for such a tremendous quantity of hydrocarbons. If the doming structure is assumed to be the cause of the accumulation, then the structure must be big enough to account for the size of the accumulation—yet these domes are altogether too small to warrant any such theory as that; and we know that outside of the 150 acres the sediments are perfectly flat. In fact, we know more; we know that the clays and sands under the domes have been washed away and are replaced by certain secondary products, due to the deposition of the salts contained in the aqueous and gaseous emanations under the domes. Therefore, there were really no sediments under that dome area to produce any oil at all, to say nothing of sediments containing carbon from organic life sufficient to produce any such quantity of petroleum.

I am referring to the origin of the oil in this instance because I would like to bring this fact strongly before the minds of the geologists who have followed the theory of organic origin of oil and gas, viz.: that if they do not study more closely the inorganic origin, they will never have the faith necessary to do this deep drilling that Capt. Lucas and I have advocated, and which Mr. Rogers has suggested.

I have referred more particularly to the salt domes, but the same remarks apply as well to all the other types of fields. In Ontario, for instance, we started to produce oil in the Corniferous limestone at a depth of 400 to 500 ft. In the '60's, almost immediately after Colonel Drake had found his first well in Pennsylvania, shallow oil was obtained in Ontario in the Corniferous limestone, and the geologists of the day, especially Sterry Hunt, studied the occurrence and gave as their opinion that the origin of the oil was indigenous and due to the animal matter of the Corniferous limestone itself. Since that time we have drilled below the Corniferous and in the lower parts of the Onondaga formation, in the Guelph and Niagara, in the Clinton, and in the Medina, we have also found large oil and gas fields.

But there is still a deeper story. In the Tilbury field, near the city of Chatham, we decided to make some exploration of the still deeper rocks on the uplift of the field. I am not speaking about the anticline, but the uplift, because the whole difference between one theory and the other is that one believes that the oil is due to accumulations along a folding,

while the other believes that it is due to emanations along the fissures of an uplift. I felt sure that there must be a great deal more oil below in that field, because in the Onondaga rocks we had a large gas field, which has produced about 100 billion cubic feet of gas up to this day, and also oil, but not in a correspondingly large quantity, only about 4,000,000 bbl. of oil at a depth of 1400 ft., the same depth and the same sand which produced the gas. I made up my mind that, all these emanations coming from below, it was a case where the gas emanations had come farther up than the oil emanations, and that we should find below much more oil to correspond to the quantity of gas that we had above. We started a deep test well and when we got down, last May, to 3165 ft., 300 ft. in the Trenton limestone, we got 6,250,000 cu. ft. of gas, with a rock pressure of 1225 lb. But after this gas well had been on the line for about a month, it was spraying oil at the rate of 100 bbl. a day. That gas and oil come from the Trenton limestone and from only 500 ft. above the crystalline Archaean rocks, and I suppose a geologist who had no faith in the inorganic origin would never have gone down to try to find such a well as that just above the crystalline rocks. Evidently there are no shales at all below the Trenton limestone, between it and the Archaean. There is only a narrow interval, about 20 ft. thick, of an arkose sand, and that is all. From the Trenton limestone we practically go right into the Archaean rocks, which are so well known in that country to the North of the Lakes.

There is an instance where the faith of the man knowing where the oil comes from made him drill deeper and deeper, even right down to the top of the Archaean; and this faith lead one whose understanding of the solfataric volcanic origin was keen to find it where it could not be expected under the organic theory. Deeper drilling is therefore shown to be intelligent exploring, and the history of all oil and gas fields has long ago confirmed the theory that, as a general rule, larger quantities of oil or gas are obtained in depth and with a greater and greater rock pressure for the gas.

Kirby Thomas, New York, N. Y.—I have had the opportunity to study the saline domes of the Gulf Coastal region in connection with investigation of the sulphur deposits associated with them in some notable instances. I wish briefly to call attention to a geologic phenomenon similar in origin to that of the domes under discussion—the salt deposits in southwest Virginia. My investigations there, made after the studies of the Texas-Louisiana domes, led to the conclusion that there was an analogy in genesis between the Virginia salt deposits and the domes. The following extract from my report on the Virginia deposits will make this relation and analogy more clear in the light of the facts concerning the dome deposits already presented:

"The conclusion as to origin, which I have formed, as a result of the study of the Saltville, Va., conditions, differ somewhat from those advanced by Mr. Stose, of the U. S. Geological Survey. It is my opinion that the Saltville deposits, both gypsum and salt, are mostly, if not altogether, secondary in character, and that they were formed through the agencies of circulating surface waters, which derived from the adjacent formations sulphuric acid from the oxidation of the iron pyrite therein and dissolved from these same, or other formations, salt which was distributed sparsely in those formations. These circulating waters were controlled in these courses by the structural conditions and by factors of elevation of their source and by the barrier formed by the overthrust of the fault. The result was a series of flowing springs along the fault in favorable localities, the waters of which springs were charged with sulphuric acid and carried salt in solution. The approach of these chemical and salt-laden waters toward the surface, and particularly the contact of the sulphuric acid waters with the soft, crushed, and probably easily dissolved masses of limestone along the fault, resulted in the deposition of gypsum, replacing the limestone, according to well known chemical formulas, and the precipitation of the salt, either from conditions of supersaturation or, as is more probable, because of the disturbance of equilibrium of the acid-salt solution by the chemical reactions noted. This assumption accounts for the limitation of the gypsum and salt deposits to a zone of narrow, but varying, width extending along the fault line and apparently in most instances dipping under the lip of the fault. The relation of the salt below the gypsum is apparently a characteristic feature of the Saltville district. The reason of this segregation and relation is not entirely easy to explain, but the similarity of this fact and relation with the conditions which exist in the salt domes of the Louisiana-Texas region is significant."

W. G. Matteson.—We all realize the value of Captain Lucas' pioneer work in the Gulf country, and when one considers that from Spindletop the development spread to Sour Lake and Jennings, and the opening up of pools in that country stimulated development at Humble, and the Caddo field, if it hadn't been for Captain Lucas' conviction that oil could be found in these domes, one might stop to speculate how much time might have elapsed before these great pools in the Gulf Coast country would have been discovered.

Concerning the developments at High Island and the fact that a number of wells have been drilled there unsuccessfully, an analogy might perhaps be drawn between High Island and Damon Mound. A number of wells have been drilled at Damon Mound, without success at first; but this last year a deep test came in for about 4000 bbl., and a second test yielded about 10,000 bbl. For a while it looked as if we

were going to open up another one of those great pools that have been found in that country. However, subsequent developments have been very discouraging. We have found oil in Damon Mound anywhere from 1800 to 3600 ft. in depth. The drilling shows that the "sands" must be tremendously broken; that you cannot depend upon their character. For instance, an operator might bring in a well at one place and move over just a short distance from there and drill a dry hole in apparently equally favorable territory. Many deep tests have proven absolutely futile.

With respect to the asphalt seeps, I have noted in going along stream-beds, that asphalt seeps will be found sometimes under the banks of the streams which have cut their channels 5 or 6 ft. below the surface, and several investigators of the Gulf Coast country have also reported asphalt seeps under similar conditions. It is quite true that the salines of the north country, of the wold region, are highly concentrated and more numerous than along the Gulf Coast, but there has been a record of numerous such springs that have been found among the salt domes of the coast prairie. Mr. William Kennedy, in an unpublished report, mentions numerous saline springs on the south side of High Island in the vicinity of the trembling marshes.

Concerning the paraffin dirt which Mr. Rogers mentions, that dirt has been analyzed, and we have not been able to make much out of it, except that it doesn't contain any paraffin, but where drilling has taken place in the vicinity of this paraffin dirt, the results have been a failure.

Mr. Rogers has stated that the development of the deep sands around the edge of the salt domes make for dangerous estimates as regards the value of acreage from the apex of the domes. I think the fact that the study of most of the salt domes of the Gulf Coast country shows the area in which production has been found to be very limited and well within the prescribed limits, as mentioned in this paper, will prove that it is dangerous to go far from the apex of the dome in development work.

It has not been my intention to enter into a vigorous discussion of the origin of salt domes. Many papers have devoted much time to that. I have intended to mention the various theories and to state which have been of considerable value in conducting field operations.

The Coastal Plain, in which the domes are situated, presents structural and stratigraphical relations very similar to those found in connection with the Virginia salt deposits, only on a much larger scale. The relation of the domes to the assumed junction of fault planes presents physical conditions similar to those concerned with the Virginia deposits. Further information concerning the Virginia deposits can be obtained in *Bulletin* No. 8 of the Virginia Survey, in an able article by George W. Stose, of the U. S. Geological Survey.

Apparently the sulphur in the domes is a chemical incident, resulting

from the reactions between the organic matter in certain limestone formations associated with some of the domes and the acid waters. The so-called "domes," from the drilling data, are really subterranean plateaus, often 100 acres or more in extent on the top and relatively flat, with very steep, sloping and irregular sides.

Chester W. Washburne, New York, N. Y. (written discussion).—The fact brought out by Mr. Rogers' discussion, that only one-tenth of the total salt will be precipitated by the cooling of the ascending salt solution, was first mentioned by Lindgren in his book on "Ore Deposits." Mr. Rogers very appropriately observes that the Harris theory needs a precipitating agent for the salt, in order to become applicable. We have to explain the precipitation of sodium chloride, and if we could get an adequate source of chlorine ions, say, magnesium chloride or calcium chloride or hydrochloric acid, we would solve this problem, so far as pure theory is concerned.

Let us suppose there is an igneous core below the present salt cores. The emanations from the intrusive core would consist in part of ammonium chloride, hydrochloric acid, magnesium and calcium chloride, and other chlorides. These chlorides, ascending from the igneous magma through a zone of fracture above the plug, would come in contact with sodium chloride waters from salt-bearing strata, thereby causing the precipitation of salt. That disposes of the objection to the theory of Professor Harris, that he has not given an adequate cause for the precipitation of salt.

It is of interest to remark that this does not explain all of our troubles. Commonly there is dolomite above the salt, which cannot easily be connected with volcanic emanations, although the emanations may contain much carbon dioxide which would retard the precipitation of carbonates from the ascending solutions.

Another objection is that there is usually a great deal of fluorine in volcanic emanations, but no traces have been reported in the waters of the Gulf Coast oil fields. I think this argument is perhaps not valid in the case of very basic igneous rocks, fluorine being most common in acid igneous rocks; sulphur largely takes its place in emanations from very basic magmas. These two objections are very strong in my opinion. We cannot explain the precipitation of the dolomite, by the interference of volcanic emanations. We cannot explain the total absence from the salt cores of boron, fluorine, and other elements common in volcanic emanations. The theoretical entrance of volcanic emanations is a convenient addition to the Harris theory only in furnishing an adequate precipitating agent of sodium chloride.

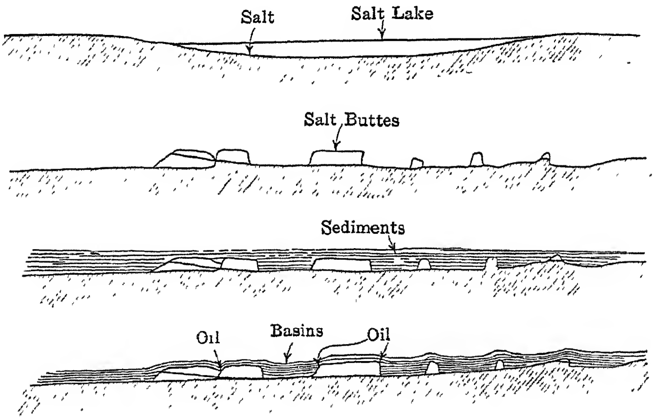
Personally, I prefer the idea expressed by Lindgren, van der Gracht, and others, that the salt cores were formed by the slow flowage of com-

pressed beds of rock-salt that lie in the Permian or other underlying strata.

I. N. KNAPP, Ardmore, Pa. (written discussion*).—It is the writer's opinion that Mr. Matteson is very much in error when he says: ". . . asphalt seeps, crude oil in springs or wells, . . . mud volcanoes, black and white alkali flats covered with alkali grasses, . . . are important geological phenomena associated with the coast prairie salt domes." This opinion is based on examinations begun by the writer and men in his employ soon after Capt. Lucas's great discovery at Spindletop, and extending along the Gulf Coast from time to time for a period of six years. No such phenomena were observed.

The writer is glad to note Capt. Lucas's correction of the record by his written discussion of Nov. 30, 1917. Also that he brings forth the matter of deep drilling of the salt domes, which I know he has consistently advocated for the last 15 years.

ANSON G. BETTS, Asheville, N. C. (written discussion†).—A theory to explain these salt domes, which perhaps does not make such demands on the imagination as the volcanic theory, is this:



Salt beds of great thickness and area were dissected by rivers, or perhaps by tidal waters, during a period of depression, leaving plateaus and buttes of the salt formation. Later, during depression and under conditions that permitted part or all of the salt buttes to remain undissolved, sediments were deposited in the valleys between the salt buttes and eventually over the whole. Still later, a slight shrinkage of the sediments caused the areas over the salt to show the elevations. As the

* Received March 26, 1918.
† Received April 16, 1918.

sediments would be left slightly inclined upward where in contact with the buried salt buttes, the oil in the sediments worked upward and collected at the edge of the salt.

William Kennedy, Fort Worth, Tex. (written discussion*).—In his discussion of this paper, Mr. Sherburne Rogers offers voluminous figures to show that the salt forming the cores of the various domes could not have been derived from sea water, and gives as an illustration the immense quantity of water required to form the salt found in the Humble dome. He refers to the theory advanced by van der Gracht apparently in support of this contention, and claims to have disposed of the views held by some that the domes were, in a great measure, formed by lateral secretion.

Van der Gracht says the immense salt plugs found throughout North Germany and other countries in that region were apparently formed by orogenic movements acting upon what he calls the Mother Bed of Salt, which he gives a thickness of about 1000 ft., and an extent of several thousand square miles. The age of this "mother bed" is given as Permian. Harris, in addition to his growing-crystal theory, also says probably a great portion of the salt found in the Coastal domes may have been derived from the salt water of Permian time. Both of these theories require an abundance of water, and consequently oppose Mr. Rogers' idea that the immensity of water required disproves the formation of the salt from that source.

I do not suppose, however, that either van der Gracht or Harris absolutely limits his view to the Permian as being the only source from which the salt could have come, but would probably agree to consider any other age as being the beginning. Although the Permian is very strongly represented throughout North Texas, we have none anywhere throughout the region from which the salt may be considered as having been derived. Many deep wells have been drilled along the eastern outcropping of the Carboniferous and each has passed directly from Cretaceous to Carboniferous formations. Thus we may eliminate the Permian as a source of salt in this region. But, although the Permian may be absent, we have with us the Carboniferous with probably a thickness of 3000 to 4000 ft., and something like 3000 ft. of Cretaceous, to say nothing of approximately 8000 ft. of Tertiary and later beds, all of which, if we may judge by the quantity and density of the waters obtained from the numerous wells drilled, carry immense quantities of salt disseminated throughout the beds; considerably more than necessary to form the cores of a great many more domes than at present known.

It is generally admitted that the presence of so much salt in the Permian is due to the presence of marine water, together with an arid climate in which evaporation was rapid, and due to this more or less

* Received Apr. 15, 1918.

concentration the salts found are localized into ponds or basin-like depressions. This condition may have occurred in Carboniferous or Cretaceous times, and even in the Tertiary, and owing to the concentration of the salt not so much water may have been required as Mr. Rogers appears to think. Solutions so concentrated as to cause deposition are quite different from seawater. The structure of the salt found in the Coastal domes shows it to be a secondary formation and has none of the earmarks of primary deposition. This, in itself, shows the elaborate calculations made by Mr. Rogers to be worthless and have no bearing whatever on the origin of the Coastal salt domes.

While the probabilities are very much against the existence of any "mother bed" of salt anywhere within this region, we may yet consider the fact that throughout it the deposits, from Carboniferous up, are all highly saliferous and that through the long migrations of the waters they, in all probability, became highly concentrated solutions carrying both lime and salt. As the domes appear to lie along lines of structural weakness, it may be possible that these, in some degree, represent the conditions required by the van der Gracht idea and may possibly have formed the basins or vents in which the salt was concentrated, and thus formed the dome. Under these conditions, not so very much water would be required. It may also be pointed out that the increasing size of the dome by the growth of the crystals would, of necessity, require concentrated solutions in connection with the core, as crystals, to grow, would require material, and this material would have to be obtained from the brines traveling through the adjacent formations. This would practically be lateral secretion.

Mr. Rogers appears to place much reliance upon the presence of the so-called paraffin dirt as an indicator of the presence of oil. It would occupy too much time and too much space even to enumerate the localities in which worthless wells have been drilled upon this symptom of the presence of oil. It has been given special prominence in wild-cat prospectuses over and over again, and incidentally over and over again the unfortunate investors' money has been lost. In many of the important pools, the presence of this so-called indication has not been noted, but it is present in many localities where drilling has shown neither oil nor gas, except in very insignificant quantities.

G. Sherburne Rogers.—(Discussion concluded on page 704.)

Some New Methods for Estimating the Future Production of Oil Wells*

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(New York Meeting, February, 1918)

CONTENTS

Introduction

Oil wells usually reach their maximum daily output shortly after they are completed. From that time they decline in production, the rapidity of decline depending on the output of the wells and on other factors governing their productivity. The production curve of a well shows the amount of oil produced per unit of time for several consecutive periods; if the conditions affecting the rate of production are not changed by outside influences, the curve will be fairly regular, and, if projected, will furnish useful knowledge as to the future production of the well. By the aid of this knowledge the value of a property may be judged, and proper depletion and depreciation charges may be made on the books of the

* Published by permission of the Director of the Bureau of Mines.
† Petroleum Technologists, U. S. Bureau of Mines.

operating company. Certain difficulties peculiar to oil production are encountered when estimating the future production of oil wells, and the oil producer has been more uncertain regarding the future production of his property than the producer of almost any other mineral.

In recent years much attention has been devoted to this problem, and considerable progress has been made in the development of methods for estimating future production. As valuable as these methods are, to the producer who knows how to use them, they still leave much to be desired in accuracy and ease of application. Methods are needed that are more dependable, that will furnish closer estimates from data obtainable early in the life of the property, that show the limitation of the estimates, and that may be quickly and easily applied. The present paper discusses some new methods which meet some of these requirements.

So far as we know, the information given is new. The methods outlined have greatly assisted us in evaluating oil properties in certain fields during the last 2 years, and if confirmed by data now being gathered in other fields, their value will be still greater. Although the deductions here presented have been derived from enough data to warrant the belief that further investigations will confirm them, some of them are advanced only tentatively.

Our indebtedness is hereby acknowledged to W. A. Williams, former Chief of the Petroleum Division of the U. S. Bureau of Mines. Under his direction, in the winter of 1915–16, the senior author undertook the work of estimating the future output of several oil properties in the Osage Indian Reservation, Oklahoma. The methods outlined in this paper were originated in the course of that work, but they have since been further developed and their usefulness demonstrated by both authors. The junior author, during the years 1916 and 1917, has been engaged in gathering and analyzing data on the rate of decline of production of average wells in all the principal oil fields of this country and the best methods for estimating the future output of oil properties, for the purpose of preparing a bulletin to be issued shortly by the U. S. Bureau of Mines. The present paper is, therefore, a forerunner of the more complete bulletin to be published by the junior author, which will give in detail much of the information upon which the conclusions in this paper are based, as well as appraisal and generalized decline curves of other important fields.

Theories Relating to the Recovery of Oil

The productivity of an oil-bearing area is the quantity of oil that can be extracted rather than the quantity contained in the productive formation, for much more oil is left underground than is ordinarily

brought to the surface. The proportion recovered from a given area depends upon the available energy for expelling the oil from the oil-bearing formation and the efficiency of this energy, which, in turn, depends upon the specific conditions affecting the well or property involved.

Our conceptions of the elements that enter into the recovery of oil are given in the following tentatively advanced outline[1] which will also give a better understanding of the factors involved in the estimation of future production:

1. *Factors governing the quantity of oil:* Area, thickness, porosity, and degree of saturation of the oil-bearing formation.

2. *Factors governing the expulsive energy (or forces):* The main force is the compressed gas associated with the oil, assisted by gravity and occasionally by direct pressure from gas or water in the same formation. Artificial factors sometimes applied are vacuum pumping, water flooding, or the use of compressed air or gas.

3. *Factors governing the efficiency of the expulsive forces:*

(*a*) Frictional resistance in the formation, depending upon its nature as well as the characteristics of the oil and the velocity of flow of the oil and gas.

(*b*) Back pressure from the atmosphere, weight of fluid column in the hole, and mechanical arrangements on the wells.

(*c*) Wastes of gas energy through lean, unproductive or depleted strata, and through inefficient operating methods.

(*d*) Marginal value of the oil.

The foregoing outline shows the variety of factors controlling the productivity of wells and indicates how they may be segregated under three main classes. The production of a well is the gage of these three principal factors for the particular conditions existing at that well. The decline curve of a well's production represents a depletion of the oil supply, a depletion of the expulsive forces, and probably a decrease in the efficiency of these expulsive forces.[2]

Ordinarily a well reaches its maximum daily output within a few days or weeks after its completion, though occasionally not until it has produced for several months. Although the ensuing decline is sometimes retarded by deeper drilling, shooting, etc., eventually the yield becomes

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[1] The senior author has discussed the theory of the expulsion of oil in *Bulletin* No 148, of the U. S. Bureau of Mines, entitled, "Methods for Increasing the Recovery of Oil."

[2] The large wells recently drilled in Butler Co., Kans., are unique exceptions to the general rule. The initial production of these wells is large and very little gas accompanies the oil. It is, therefore, improbable that gas, in this case, is the principal expulsive force. The lack of gas and the fact that water under pressure closely underlies the oil, and that most of the wells quickly show water, indicate that direct water pressure, and not gas, is probably the impelling force in this field.

so small that it is unprofitable. This so-called exhaustion of the well represents the exhaustion of the expulsive forces rather than that of the oil content, of which much more may usually be recovered in regions where the character of the sand is favorable for the use of artificial expulsive forces, such as compressed air, water-flooding, or gas (vacuum) pumps. The decline of a well's production is usually coincident with the decline of its gas pressure, and the latter indicates the depletion of the principal expulsive force. The intimate relation of oil recovery to the gas contained, and the efficiency of the latter in the expulsion of the oil, warrants a closer study of this phase of oil production. More knowledge on this subject would undoubtedly greatly assist in estimating the production and decline of oil wells.

Methods Commonly Employed for the Estimation of Future Production

The future production of oil properties has been estimated in three principal ways: (1) the saturation method, which is based on calculating the porosity of the productive sand; (2) the production curve method, which consists in determining, from the decline in production in the past, the amount of oil that will be produced in the future; and (3) the production per acre method, by which the future production is estimated by comparing actual recoveries per acre from similar properties in the same or in a comparable district.

Saturation Method

The factors used in the first method are the porosity, the thickness, the extent, and the saturation of the oil sand. The percentage of oil recoverable is then estimated. The capacity of the oil sands, where uniform conditions of thickness and porosity exist, can be determined with fair accuracy from well records if porosity determinations be made from a number of representative samples, but when an attempt is made to determine the degree of saturation of the sand or the percentage of recoverable oil to the total amount, many difficulties and uncertainties appear, which, in the past, have led to serious errors. The value of the recovery factor is controlled by all the variables involved in the productivity of an area (see p. 494), a condition which makes the assignment of an arbitrary value for a specific property hazardous. If these variables could be satisfactorily and easily determined, this method would be very satisfactory, as a single well on a property makes available some of the evidence on which an estimate of future production can be based, provided, of course, the assumption is made that the porosity and thickness of the productive sand are fairly uniform.

Production Curve Method

The second method is based on the record of production of the wells themselves. As the past production of a well is an index of the quantity of recoverable oil rather than of the total oil content, a determination of the relative proportion of the recoverable oil is unnecessary.

In using this method, the production of the well for time periods is plotted for as long as the well has produced, and to estimate the future production the curve thus obtained is projected from the terminal to the point representing the minimum production to which the well can be pumped with profit.

The production of a property is the composite production of the individual wells, and it is frequently necessary to use the record of the entire property because production records of individual wells are not always kept. If all the wells were completed at the same time, the production curve of the property would be a composite decline curve of the production of all the wells. However, all the wells on a property are rarely drilled at once, and as a result the production of the property generally increases with each new well until the later wells can no longer offset the combined decline of the older wells. The production of the whole property then begins to decline. A decline curve derived by plotting the average production of the wells on such a property is often misleading because the flush productions of newer wells sustain unduly the average production of all, though this is partly compensated by the usual decrease in initial productions of succeeding wells (Fig. 6). If a property is gradually developed, the later wells generally show successively smaller initial productions, because the gas pressure, to a considerable extent, and the oil content, to a less extent, have both been reduced by the older wells. If all the wells have been drilled at nearly the same time, however, the average production per well may be used to construct an average curve. This method is often preferable, as it results in the elimination of irregularities and peculiarities of individual wells and gives the average decline under the conditions existing on the property. But where the development has been very irregular, and spread over a long period of time, such a record may be unsatisfactory, and lead to erroneous conclusions. Experience has shown, however, that unless the development has been very irregular, average curves can be derived without introducing much error.

Production per Acre Method

The third method is to reduce the actual production of exhausted properties, or of properties so nearly exhausted that their ultimate productions can be estimated with fair accuracy, to a basis of recovery per acre or per acre-foot and to apply these values to other similar proper-

ties, from which approximately the same ultimate production may reasonably be expected. This method is particularly valuable in estimating the recoverable oil of whole fields or districts, representative parts of which have produced long enough to justify an estimate of their total output. As with any other method, however, considerable judgment is required in the use of this method.

The several methods for estimating future production have here been treated very briefly, and for further information the reader is referred to the recent excellent paper by R. W. Pack.[3]

The advantages and disadvantages of the methods may be summarized as follows:

The saturation method, so called, requires data either difficult or impossible to obtain, particularly the recovery factor and, in the absence of trustworthy records and experimental data on the porosity of the productive sand, involves the necessity of assuming values for most of the factors controlling the productivity of a well. This method can be considered neither accurate nor dependable, and unless sufficient data are at hand to warrant a fairly accurate determination of the necessary factors, it should be used only where data for applying the other methods are not obtainable, and even then for making only rough preliminary estimates.

Experience has shown the production-curve method to be the most satisfactory so far developed and this method, with various modifications, is consequently in most general use. However, it is still far from what is needed in accuracy, ease and quickness of application, and knowledge of the limitations in the accuracy of the estimates made. This method also has the disadvantage of requiring consistent records extending over several years. This often involves much labor and care in collecting the necessary information and in making and extending the curves.

The estimation of ultimate production per acre from the recoveries obtained from similar older properties is possible only where records of the ultimate production of such comparable properties are available or where the ultimate yield can be estimated by projecting the production curves. The method is most useful when applied to the estimation of the ultimate production of entire fields.

In spite of the progress that has been made in recent years in estimating the future production of oil properties, a review of the methods in use discloses an obvious need for still better methods that are more accurate and easier of application, and from which both the probabilities and the limitations of the accuracy of the estimated future output of a well may be known. It is hoped that the methods outlined in this paper will point the way to a closer approach to these ideals.

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[3] The Estimation of Petroleum Reserves. *Trans.* (1917), **57**, 968.

Appraisal Curves[4]

Derivation and Construction

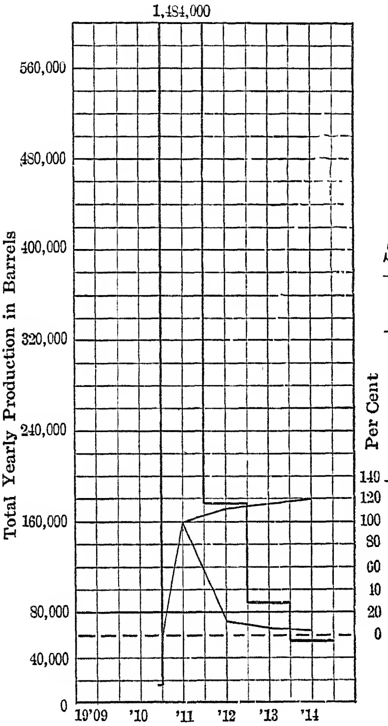
In developing the following methods for the estimation of the amount of oil that can be obtained from a property under given conditions, the production records of many properties in two oil districts in northeastern Oklahoma have been studied. The first is in the eastern half of the Osage Indian Reservation, and the records represent properties scattered over a district about 60 miles (96 km.) long by 20 miles wide. Over such a large area there is a great variety of oil-sand depths, sand conditions, etc., and many kinds of data for the preparation of production curves are, therefore, available. The records from 68 of these properties, including more than 1000 wells, were studied, analyzed, and used in the determination of the results presented. For the purpose of comparison, 64 properties including 675 productive wells were also studied in the Nowata Field, which lies about 25 miles east of the Osage Reservation. Because the productive sand in the Nowata district is much more uniform in depth, and conditions throughout the field are more regular than in the Osage Reservation, and because the properties studied are practically in one pool, much more uniform results were obtained from them than were possible from the widely distributed properties studied in the Osage Reservation.

The records of the properties in these fields gave the production by years and the number of wells producing each year; records of individual wells could not be obtained. From the records available, the average daily production per well during each year was computed. The figures of average daily production of properties not too confused by irregularity of development were reduced to percentages, the average daily production for the initial year being assumed as 100 per cent. and the average daily well productions for succeeding years being expressed in percentages of the first year's average daily production. Thus, if the daily production per well was: first year, 25 bbl.; second year, 15 bbl.; third year, 10 bbl.; the percentage record would read, 100 per cent., 60 per cent., and 40 per cent., respectively. These percentages, instead of the average daily production, were plotted on rectangular coördinate paper, and the resulting percentage decline curve was projected to estimate future annual productions in percentages of the first year's production. The minimum profitable daily production was assumed as 1 bbl. per well in the Osage Reservation and ½ bbl. per well in the Nowata Field. The method of plotting these percentages on cross-section paper

[4] The name "appraisal curves" has been given by the authors to the curves described, because of their use in determining the amount of oil that may be expected from a property, which is one of the most important factors in appraising the monetary value of an oil property.

is illustrated in Fig. 1 and 2, which represent the curves of two typical Osage properties. The heavy curve in these figures represents the total production of the property. Fig. 3 is the curve of a typical property in the Nowata Field, showing also the form devised for keeping production data.

From the percentage decline curves, cumulative percentage curves were constructed by adding the past percentages of each successive year,



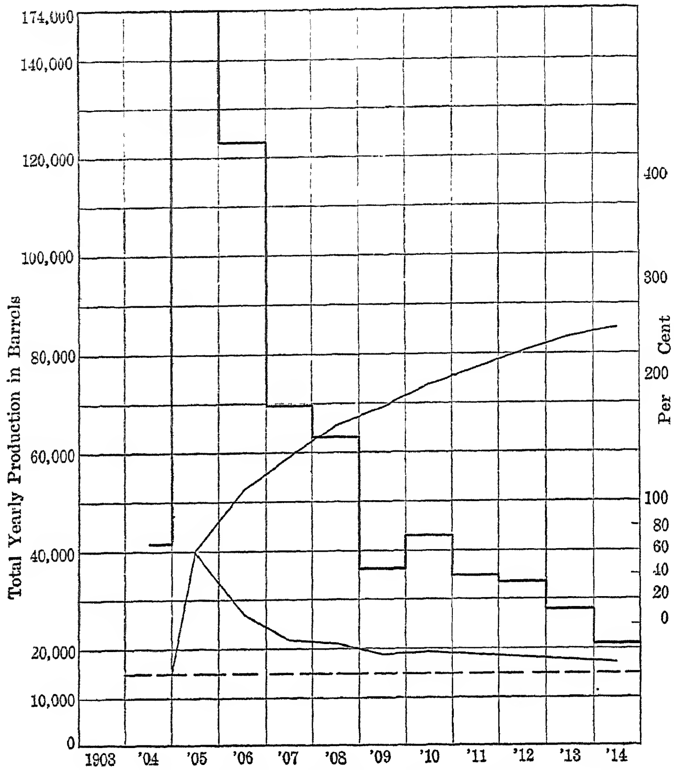
Section 19—21—9, *Finance Oil Co., Osage*

Per Cent	Bbl Per Well-day	Year	Production	Wells
...	...	Dec. 1910	16,975	.
100	177	1911	1,484,293	23
11	20	1912	175,554	24
5	10	1913	87,086	24
4	6.5	1914	56,324	24

FIG. 1.—EXAMPLE OF WELLS OF LARGE PRODUCTION IN THE OSAGE INDIAN RESERVATION, SHOWING THE METHOD OF COMPUTING PERCENTAGE DECLINE AND CUMULATIVE PERCENTAGE CURVES.

as in Fig. 1, 2, and 3. Thus, using the figures previously given, the cumulative percentage curve reads 100 per cent. the first year, 160 per cent. the second year, 200 per cent. the third year, and so on. The termination of the projected curve is the point where the well reaches its minimum economical production. The cumulative percentage at this point is the percentage that the ultimate production is to the production of the initial year. Thus, calculations based on the projected curve of a group of wells showing a total cumulative of 400 per cent., indicates when applied to a single well that a total of four times the production of the first year should be obtained by the time the well reaches its minimum limit of profitable production.

Fig. 1 and 2 show the form in which the data for the properties of the Osage Reservat ion were kept. Fig. 3 shows the form later devised and in



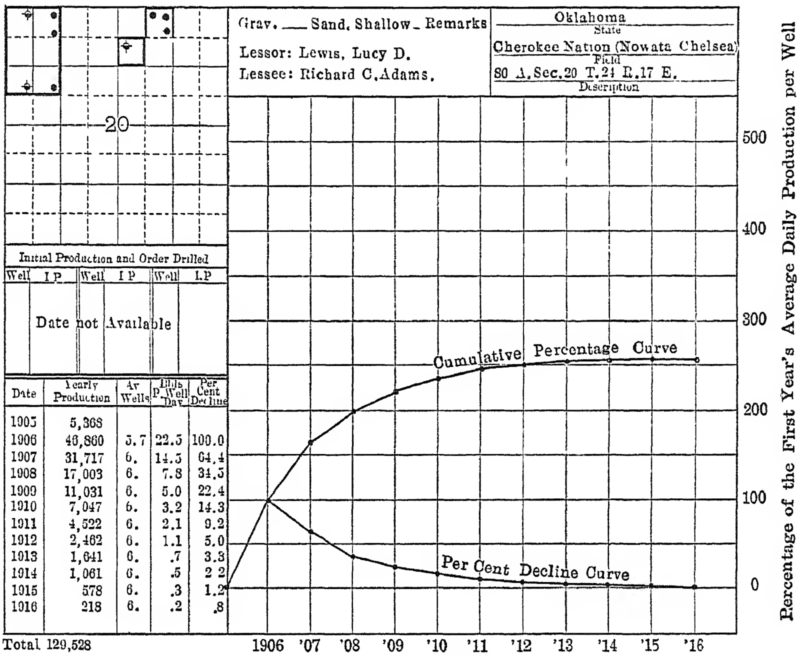
Lot 49, Barnsdall Oil Co., Osage

Per Cent.	Bbl Per Well-day	Date	Production	Wells
.....	....	July, 1904	41,694	..
100 0	23.9	Year 1905	174,085	20
48 5	11.6	Year 1906	123,506	29
27 2	6 5	Year 1907	69,707	29
24.7	5 9	Year 1908	62,768	29
15.1	3.6	Year 1909	36,460	28
17.5	4.2	Year 1910	42,875	28
14 3	3.4	Year 1911	35,009	28
13.7	3.3	Year 1912	33,522	28
11.5	2.7	Year 1913	27,984	28
8.5	2 0	Year 1914	20,845	28

Fig. 2.—Example of wells of small production in the Osage Indian Reservation, showing method of computing percentage decline and cumulative percentage curves.

present use for working up production data. These figures show the percentage decline curves and the cumulative percentage curves of two properties in the Osage Reservation and one property in the Nowata Field.

The purpose of reducing the production records to percentages was to provide a basis for comparing wells of different capacities. A study of these curves showed that the larger wells have a tendency to sharper declines than small wells, and hence smaller cumulative percentages. For example, the average daily production per well on the property represented by Fig. 1 is 177 bbl. The total cumulative percentage, for as long as the record was obtainable, was 120 per cent. The average daily well production of the property represented in Fig. 2 is 23.9 bbl. and the total cumulative percentage is 281 per cent.



	Date	Yearly Production	Av Wells	Bbls P. Well Day	Per Cent Decline
Oct.	1905	5,368			
	1906	46,860	5.7	22.5	100.0
	1907	31,717	6.	14.5	64.4
	1908	17,003	6.	7.8	34.5
	1909	11,031	6.	5.0	22.4
	1910	7,047	6.	3.2	14.3
	1911	4,522	6.	2.1	9.2
	1912	2,462	6.	1.1	5.0
	1913	1,641	6.	.7	3.3
	1914	1,061	6.	.5	2 2
	1915	578	6.	.3	1.2
	1916	218	6.	.2	.8

Total 129,528

FIG. 3.—EXAMPLE OF WELLS IN THE NOWATA FIELD, SHOWING METHOD OF COMPUTING PERCENTAGE DECLINE AND CUMULATIVE PERCENTAGE CURVES.

In order to make a systematic comparison, the average initial production (average daily production per well during the first year) of the wells on each of the 68 Osage properties was plotted against the total cumulative percentage of that property. Thus each dot on Fig. 4 represents the total cumulative percentage of a property with a certain average daily production per well the first year. After all the properties were represented, the numerical average of the dots between each set of vertical lines was obtained. These average points were then connected by lines which made an irregular curve from which the curve representing the average total cumulative percentages was generalized. The maximum and minimum cumulative percentage curves were then drawn in,

their location being determined by the outermost dots. The maximum, average, and minimum total-production curves were derived from the three curves just discussed. Their use will be explained later.

Similarly, the relation of initial production to the total cumulative percentages in the Nowata Field was shown by plotting data from 64 of the most regularly developed properties in that field (Fig. 5). It should be noted that the scale used in Fig. 5 is not the same as that in Fig. 4.

This relation of the total cumulative percentage of the average well on a property to the average initial production is very striking. There is a marked tendency for the larger wells to have small cumulative percentages, indicating more rapid declines; and conversely, the smaller the well, the more gradual the decline and the larger the cumulative percentage, with the exception of very small wells whose initial productions were already near the profitable minimum production. From Fig. 4 it will be seen that in the Osage Reservation the average 10-bbl. well shows 420 per cent. total cumulative, whereas the average 250-bbl. well shows only 150 per cent. total cumulative.

It will be observed from Fig. 4 and 5 that wells of the same output during the first year may show considerable variation in their total cumulative percentages though restricted within well defined limits; for example, a 25-bbl. well in the Nowata Field (Fig. 5) might show a minimum total cumulative of 135 per cent., a maximum of 250 per cent. and an average of 190 per cent. The operator could, therefore, estimate with reasonable certainty that with his wells averaging 25 bbl. daily each the first year, he would most likely obtain 90 per cent. more, certainly at least 35 per cent. more, and possibly 150 per cent. more. This condition is in accordance with the observed fact that wells of the same initial yield may decline at different rates and will, therefore, afford different ultimate productions. It will be seen, however, that there are distinct maximum and minimum limits. In the figures, these limits are shown to extend along either side of the average curve. It will likewise be observed that there is considerable regularity in the variation or deviation from this average and, in the parts of the curve affected by the greatest number of records, there is a distinct tendency to bunch along the line of averages. This is particularly noticeable in the Nowata appraisal curve, Fig. 5.

If, in the future, a group of wells should be drilled in the eastern part of the Osage Reservation or in the Nowata Field, their average production can confidently be expected to fall, with few possible exceptions, within the maximum and minimum limits of these curves and, in the majority of cases, nearer to the average than to either of the extremes. The curves shown in Fig. 4 and 5, therefore, indicate the probable limits of the productivity of wells of various sizes in these two fields.

Although the cumulative percentages are less for the larger wells,

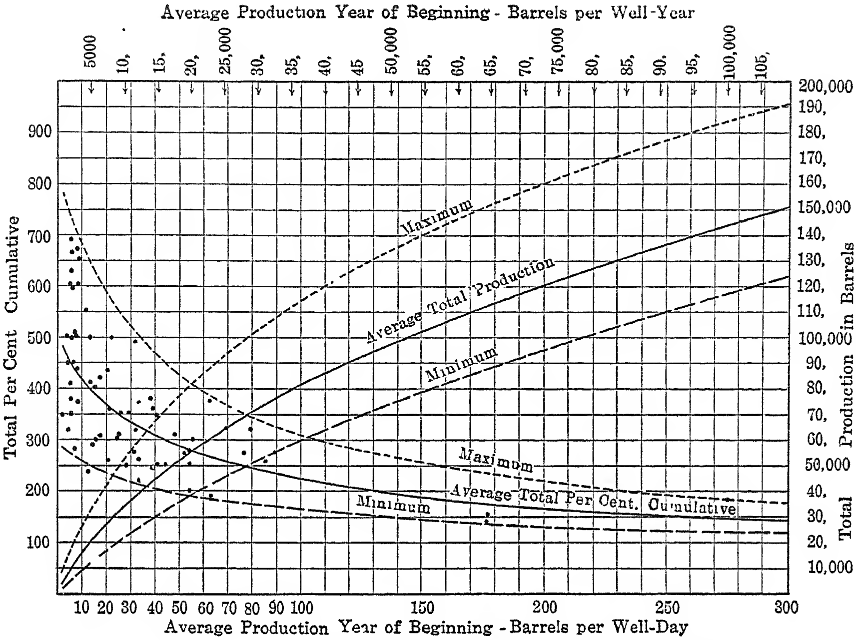


FIG. 4.—APPRAISAL CURVE FOR WELLS IN THE OSAGE INDIAN RESERVATION, OKLAHOMA.

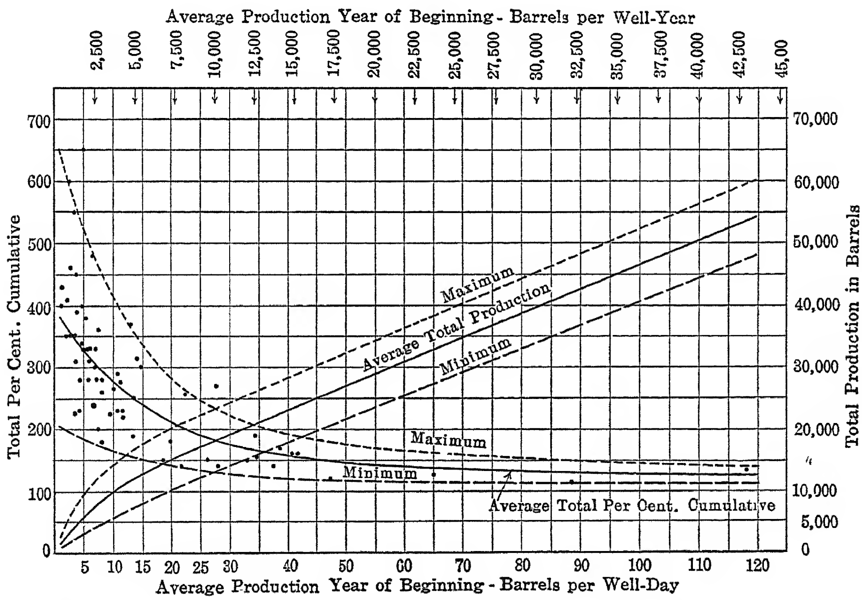


FIG. 5.—APPRAISAL CURVE FOR WELLS IN THE NOWATA FIELD, OKLAHOMA.

the actual total production of such wells is large and is usually in direct relation to the initial yield of such wells. This fact is well shown in the curves of total production in Fig. 4 and 5, plotted to bring out this relation by multiplying the first year's production of wells of various initial capacities by their respective cumulative percentages. Thus, on the Osage curve a well that produces 25 bbl. daily produces about 9000 bbl. a year. On the average, such a well has a cumulative percentage of 350 per cent., giving an estimated total production of about 32,000 bbl. The same total-production curve could have been constructed directly by plotting the total productions to date plus the estimated future productions of the average well for each property.

From these curves, with the first year's production of a well or a group of wells given, it is possible to determine the minimum amount of oil that in all probability will be produced, the maximum that one may expect, and the amount that the average well of corresponding initial yield will ultimately produce.

It must be remembered that these and the following deductions are based on a sufficient number of well records to show what are the *average* and what are the *unusual* wells. Almost any operator can cite instances of extraordinary or freakish wells that seemingly show the futility of attempting the estimation of future production. For example, some wells, instead of declining, show sustained or even increasing production for several years; other wells may cease producing suddenly but sometimes begin again after many months or years; sudden increase in the production of old wells may occasionally be noted; or the life of a well may be abruptly terminated by accident or water infiltration.

Obviously there will be exceptional wells to which these deductions can not be applied nor does there seem any possibility of forecasting the behavior of such wells no matter how much information may be available, but, though freakish wells may be common in some fields, as in the Gulf Coast Field, they are comparatively rare in the majority of fields as is indeed denoted by the use of the descriptive terms "extraordinary" and "freakish." The very fact that they are out of the ordinary is what attracts the general interest in them and distorts their relative importance. Among many wells the "freaks" will be averaged out as in the present investigation. In Fig. 4 and 5, which include nearly 2000 wells, it is evident that freak wells have little influence, and that the extremes, which represent the unusual wells, arrange themselves in a most systematic manner.

In these deductions both the laws of averages and of probabilities have been employed as in insurance but, in the production curve methods previously used only the laws of averages have been employed. To illustrate the principles; among 10,000 men the average height will be 5 ft. 8 in. but there may be one man 7 ft. tall and another only 4 ft. tall.

These two men will represent the two extremes that may be expected among that number of men, their mean height being practically the same as the average. For any man at random, the probabilities are that he will be about 5 ft. 8 in. and only once in 10,000 times that he will be 7 ft. or 4 ft. tall. Nevertheless, it will be these two extremes out of the 10,000 that will attract attention and be remembered.

Comparison of Appraisal Curves of the Osage and Nowata Fields

It will be observed that the range of expectations is much narrower and lower for wells in the Nowata Field than for Osage wells, enabling one to forecast within narrower limits the probable future production of a well of which the first year's production is known.

For all wells having an initial yield greater than 30 bbl., the maximum cumulative percentage curve for wells in the Nowata Field lies below the minimum for the Osage district. For example, the maximum cumulative percentage of wells of 30 bbl. in the Nowata Field is about 225 per cent. that is, a well making 30 bbl. daily the first year in the Nowata Field will ultimately make *not more* than 2¼ times the first year's production, whereas the minimum cumulative percentage of a 30-bbl. well in the Osage Reservation is 225 per cent.; that is, a well of this size in the Osage will make ultimately *at least* 2¼ times the first year's production. A well making 100 bbl. daily the first year in the Nowata Field, on the average, will make ultimately about 1.3 times the first year's production, whereas a well of the same size in the Osage Reservation will furnish about 2.3 times the first year's production.

To understand the significance of the differences between the two curves, the differences between the two districts should be considered. The Osage records were obtained from properties in many different pools scattered through a district about 60 miles (96 km.) long by 20 miles wide. Production in this district comes mostly from the Bartlesville sand, which ranges from 1500 to 2500 ft. (457 to 762 m.) in depth. The average drainage area for each well is about 10 acres (4 ha.). In the Nowata Field, production is likewise obtained mostly from the Bartlesville sand, reached here at depths of 300 to 800 ft. (91 to 243 m.), and the drainage area of individual wells probably averages less than 5 acres. The latter district is practically one pool and conditions are much more uniform than in the Osage district. The Nowata oil is of nearly the same gravity as that of the Osage Reservation, but the original gas pressure was much lower, for in Oklahoma the gas pressures are roughly proportionate to well depths. Furthermore, the oil sands are probably thinner in the Nowata field than in the Osage, but of the differences in character of the sand, little is known.

Apparently the narrower range in variations in the Nowata curve is

attributable to the more uniform conditions, whereas the smaller future output of wells of the same initial production may be explained by the lower gas pressure, closer spacing, and the thinner sands. The fact that the appraisal curves do show systematic variation in relation to these different conditions leads one to believe that much may be done in narrowing the limits in the forecast of a well by studying local conditions in the manner suggested in later paragraphs.

Use of Appraisal Curves

After the appraisal curves have been prepared, and it is desired to determine the future output of a property, the past production of which is known, the procedure is as follows:

Take, for example, a group of wells in the Osage Reservation which averaged 20 bbl. daily during the first year; the maximum, average, and minimum future production of the average well may be obtained by following the 20-bbl. line from the lower left-hand corner of Fig. 4 to its intersections with the maximum, average, and minimum total percentage cumulative curves. These percentages may be read direct from the left margin. They are 590 per cent., 370 per cent., and 240 per cent., respectively. In other words, a well which averaged 20 bbl. per day the first year—7300 bbl. for the whole year—will ultimately make *not more* than 5.9 times 7300 bbl., *an average* of 3.7 times 7300 bbl., but *at least* 2.4 times 7300 bbl. This gives a maximum ultimate production of 43,000 bbl., an average ultimate production of 27,000 bbl., and a minimum ultimate production of 17,500 bbl. These ultimate productions, of course, include the first year's production, or 7300 bbl. Deducting this first year's production from the ultimate production figures just obtained, the future production of a 20-bbl. well in the eastern part of the Osage Reservation will be: maximum, 35,700 bbl.; average, 19,700 bbl.; and, minimum, 10,200 bbl.

These future production figures may be obtained also by first deducting 100 per cent. from the maximum, average, and minimum cumulative percentages, respectively, and then by multiplying 7300 bbl.—the first year's production—by the remainders, which in this case would be 490 per cent., 270 per cent., and 140 per cent., respectively. To obviate so much calculation, however, the maximum, average, and minimum *total production curves* were prepared (Fig. 4). From these total production curves the ultimate production may be read direct, after which the first year's production may be subtracted. Taking the same example, the maximum, average, and minimum total (or ultimate) productions of a 20-bbl. well in the Osage Reservation would be 43,000, 27,000, and 17,500, respectively. To determine the future productions, the first year's production—7300 bbl.—is subtracted from these figures, giving maximum, average, and

minimum future productions of 35,700 bbl., 19,700 bbl., and 10,200 bbl., respectively, or the same figures obtained by the other method.

As has been noted, there are considerable variations in the future productions of individual wells or groups of wells of the same initial capacities. For the 20-bbl. wells in the Osage, the deviation from the average may be as much as 35 per cent. toward the minimum or 60 per cent. toward the maximum. These variations are due to the differences in the rates of decline of wells of the same size and of different sizes (Fig. 9). A well having a rapid decline rate will produce ultimately much less than a well of the same initial output with a slow decline rate. In other words, if two wells of rapid and slow decline rates, respectively, are to produce ultimately the same amounts of oil, the well of the rapid decline rate must start in at a greater initial production than the one with the slow decline rate.

Considering the derivation of the data and the systematic and consistent manner in which they arrange themselves in Fig. 4 and 5, it is believed that much confidence may be placed in the appraisal curves given and that the ultimate production of a group of wells in the eastern part of the Osage Reservation or in the Nowata Field may be expected to fall within the extremes. Fig. 4 and 5 thus provide both the average and the limitations for productions of wells of varying output in the Osage and Nowata Fields, respectively; and, after the first year's production has been obtained from a given group of wells, the operator can be reasonably sure that he must not expect more than a certain amount nor less than another amount. This will hold provided the wells are not deepened, cut short by water troubles, or by any radical change from the conditions prevailing during the first year. He will know that his wells are more likely to approach the average than either extreme and if he forecasts his production on this basis it provides a dependable method for estimating the future production of his property. By the law of averages, the chances of attaining the average are better with a number of properties than with one small property, and particularly with an individual well. By methods given later, it will be shown that it is possible for the operator to determine whether his wells are above or below the average, and how much he should allow one way or the other in estimating future output.

In the practical application of the appraisal curve, the user may possess a property either fully or partially drilled. If the property is completely developed, the future production can be estimated from the average production per well, but if the property is partially developed, the future production of the undrilled wells must be estimated as well as that of the producing wells.

To determine the prospective value of the undrilled portion of the property is essentially a problem in petroleum geology, which involves the

questions of determining the number of productive wells that the undrilled portion of the property will support and whether the underground conditions are similar to those of the developed portion of the property. In addition, an estimate must be made of the probable effect of the producing wells on the new wells, which are influenced by natural conditions, spacing of the wells, and the length of time the older wells have been producing. After considering the weight to be attached to each of these factors, the person making the estimate must decide how productive, compared to the developed portion, the undrilled locations will probably be. In arriving at this decision, estimates of the ultimate productions of the producing wells will be of greatest assistance in determining the recoverable oil per acre. In the same way, a knowledge of the acreage recoveries of oil from other properties in the same district will aid in estimating the probable oil recoveries per acre from the undrilled portion of the property.

Accuracy of the Appraisal Curves and their Sources of Error

In plotting such curves as Fig. 4 and 5, judgment must be used in selecting and applying the records, for there are sources of error and confusion that must be avoided so far as possible or allowances made for them. With care and study, this can be done, for, with the many records used, the errors tend to compensate and to strike an average. Moreover, there are methods of reducing the chance of error, outlined later in this paper, which will allow closer estimations.

A source of error which would not enter if records of individual wells were available, or if all wells were drilled at approximately the same time, is that later wells retard the average rate of decline of all the wells by their initial flush productions. The errors introduced in this manner, however, are often not as great as might be thought, especially in such fields as are found in Oklahoma, for there is a strong tendency for initial production of new wells near old wells to become constantly smaller as time goes on, on account of well interference, so that they drop into the general average soon after completion. The consecutive yearly decrease in initial production of several properties in the Glenn Pool, Oklahoma, is clearly illustrated in Fig. 6. In 1907, it will be seen that the average daily production of 20 wells drilled in the Glenn Pool was about 108 bbl. In 1908, 23 new wells averaged about 78 bbl. daily. Likewise, the average daily production of 67 wells completed in 1909 was about 57 bbl., and so on.

The abandonment of wells of small output on a property will likewise tend to keep up the average production per well, and in the later life of a property this occasionally has a noticeable effect on the production curve.

A compensating source of error for the later life of a property is

the assumed economic limit of production. On account of the increase in the price of oil, this limit may prove too high, and it may be possible to pump the wells profitably to a smaller production. For wells of large initial yield, this additional production will be so small compared to the total that the error in percentages of the first year's production is negligible, but for wells of small initial yield the error in cumulative percentage would be of considerable importance. As has been shown, the cumulative percentage compared to the first year's production varies inversely with the initial yearly output of the well. The cumulative percentage of a 2-bbl. well in the Osage may be as much as 700 per cent.

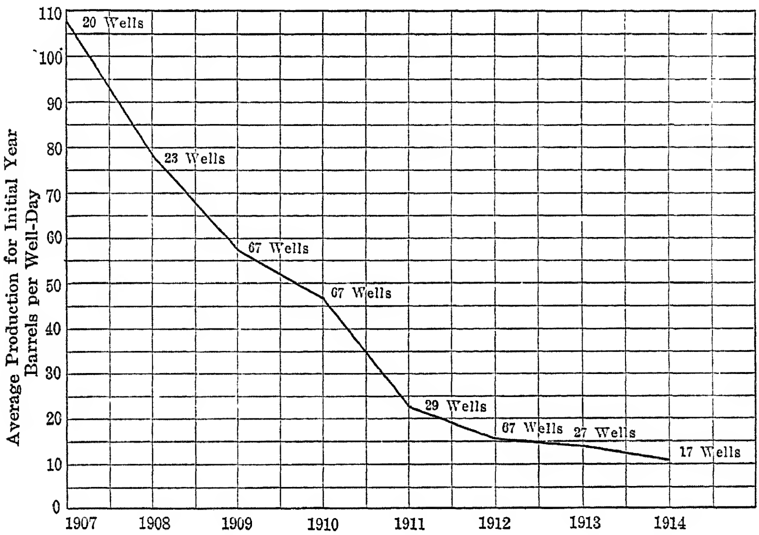


FIG. 6.—DECREASE IN AVERAGE DAILY PRODUCTION FOR THE FIRST YEAR OF SEVERAL WELLS DRILLED DURING CONSECUTIVE YEARS IN THE GLENN POOL, OKLAHOMA.

when the well is considered unprofitable after it reaches a daily production of 1 bbl.; if the lower limit were 0.1 bbl., the cumulative percentage would be much greater.

Other sources of error lie in the alterable factors of recovery, to which attention has been previously directed. These may, during the lives of the wells, cause changes in the total recoveries and in the decline curves. Among such alterable conditions are new wells, manner of operation, economic minimum of production, stimulation by compressed air, "shooting," vacuum pumps, influx of water, etc. In most cases, these changes will increase the ultimate production as well as the rate at which the oil is obtained. The estimator cannot foretell what changes will be made nor the precise effects they will have, yet our experiences lead us to believe that in general the changes affect the

totals less than is commonly supposed except for wells which have reached very small productions.

Considering all sources of error, it is probable that the Osage appraisal curve is somewhat optimistic because on some properties the wells were drilled over a period of several years, the later wells retarding the rate of decline. The Nowata appraisal curve is believed to be more accurate, because most of the properties from which the data for its construction were obtained were completely drilled the first year.

Relations Between Future Production of Wells of Equal Output

The use of Fig. 4 and 5 is based on the average daily production per well on a property the first year. It is obvious that it would be advantageous to use the most recent year's production as the basis of estimation, regardless of the age of the wells, but the curves could not be so used unless the future production of wells of equal output on the average was approximately the same.

To determine the relation existing between the future productions of wells of equal output but of different ages, Fig. 7 was constructed by plotting wells averaging 2 to 7 bbl. daily against their total cumulative percentages along vertical lines representing their ages. Thus the cumulative percentages of wells that made 2 to 7 bbl. daily during their initial year were plotted along the first line, the cumulative percentages of 2 to 7 bbl. wells 2 years old along the second line, and so on. It will be seen that the dots representing the different wells form in bunches not far from the average line, which is approximately horizontal. The fact that the dotted line representing the average is nearly horizontal indicates that the future production of wells making 2 to 7 bbl. was practically the same regardless of the ages of the wells. The average line trends in general slightly upward, but this increase in cumulative percentage is so slight as to be practically negligible. In fact, were the first year omitted, the average line would be practically horizontal It is believed that the low-average cumulative percentage of the first year is due to lack of data. Very likely if several hundred properties were plotted in this manner, the line would much more nearly approach horizontality. In Fig. 8 is given similar proof for wells of different sizes from the Osage Reservation, the Nowata Field, and the Glenn Pool, Okla. Sufficient data were not available to work out similar proof for wells producing more than 12 bbl. daily, but there is no reason to believe that the fact will not hold for large as well as for small wells. In fact, this is indicated in Fig. 9, which is discussed in subsequent paragraphs.

The conclusion that wells of equal output on the average will produce equal amounts of oil in the future, regardless of the ages of the wells, was arrived at independently by the junior and senior authors

by the use of different methods. Although contrary to popular belief and to the prevalent ideas on "settled productions," nevertheless, the proof seems sufficient and appears to be fully confirmed by Fig. 9. The fact is of much importance and simplifies the problem of estimating future productions, for the usefulness of the appraisal curves in Fig. 4 and 5 is greatly extended because the latest year's production can be

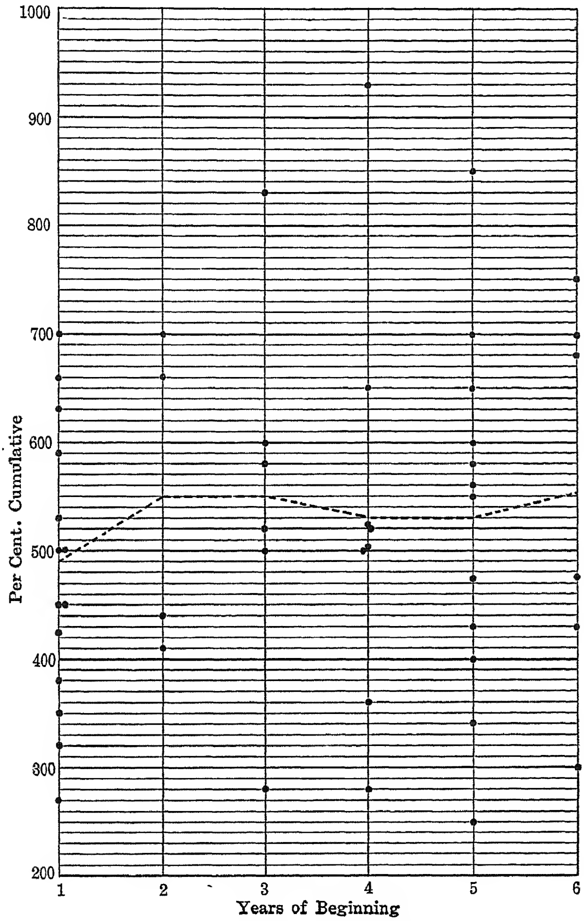


Fig. 7.—Method of demonstrating that the future production of wells of equal output, on the average, is approximately the same regardless of the ages of the wells.

used instead of the production for the first year. Furthermore, the fact that wells of the same output on the average have the same future production, regardless of age, provides a basis for estimating the production for each year of the future until the property is exhausted. Also, if this is true, the wells, on the average, will reach the economic limit at about the same time, and should decline on approximately the same curve, and have equal lives.

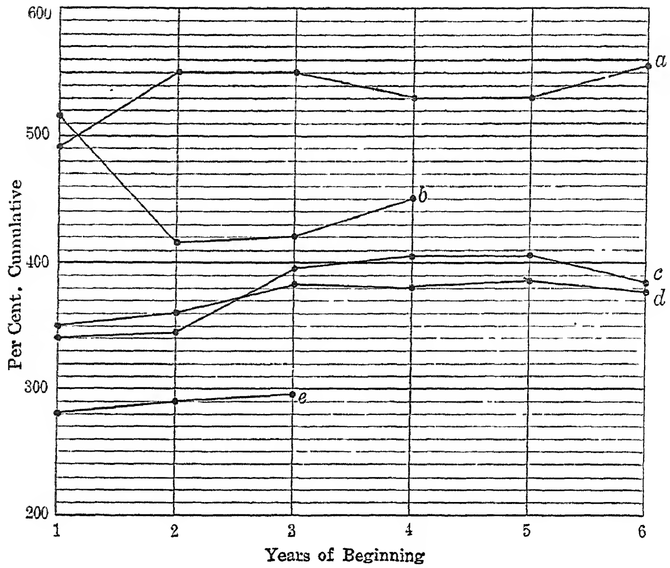


FIG. 8.—PROOF THAT WELLS IN OKLAHOMA, ON THE AVERAGE, HAVE APPROXIMATELY THE SAME FUTURE PRODUCTION, REGARDLESS OF AGE, IF OF THE SAME SIZE. a = Osage wells, 2–7 bbl. daily. b = Osage wells, 8–12 bbl. daily. c = Glenn Pool wells, 5-10 bbl daily. d = Nowata wells, 2–5 bbl. daily. e = Nowata wells, 6–10 bbl daily.

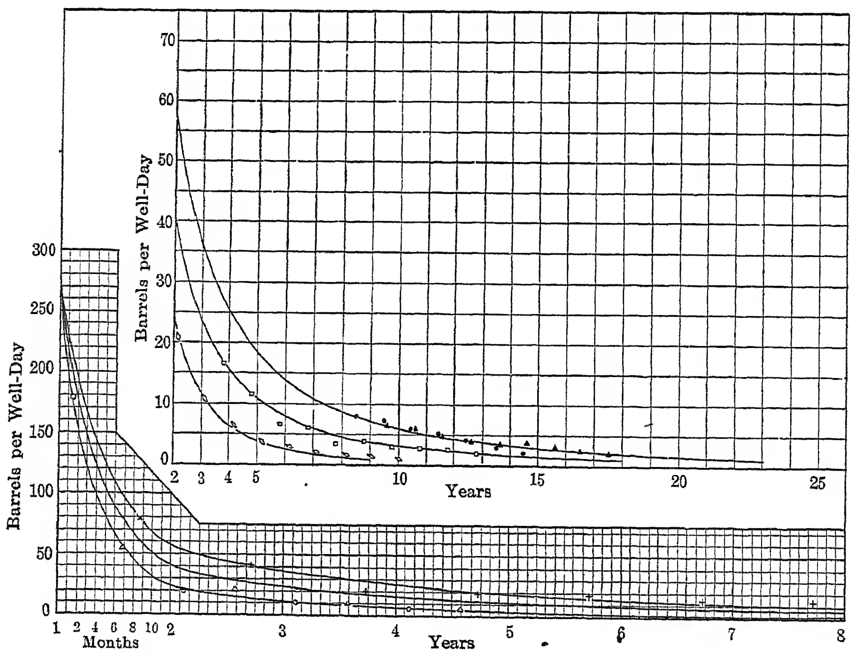


FIG. 9.—GENERALIZED DECLINE PRODUCTION CURVES OF THE OSAGE RESERVATION ON WHICH ARE SHOWN ACTUAL PRODUCTION DECLINES OF SEVEN TYPICAL PROPERTIES.

It must again be brought out that these conclusions are based on averages for certain Oklahoma districts. They do not mean that the futures of two groups of wells of the same current output must necessarily be the same; for, as shown by the dots in Fig. 7, there is exactly the same chance for variation among individuals or small groups—within certain limits—as has been shown to be the case where the productions of the initial years have been compared, as in Fig. 4 and 5. But it does mean that if the two individuals or groups have wells of the same character—say maximum on Fig. 4—their futures will most probably approximate the same, whereas if unlike in character, one being minimum, the futures will be unlike to the same extent. It also means that, if nothing of their character is known, the futures of wells of equal output, are by the law of chances, equal.

The authors are conscious that the evidence produced does not extend to wells outside of Oklahoma nor larger than 12 bbl. production daily. Though it appears logical from reasons later put forth that the conclusions will in the main hold true everywhere and for wells of all sizes this statement is not yet warranted and will not be until adequately supported by detailed proof.

Use of Appraisal Curves for the Derivation of Generalized Future Decline Curves

From the above conclusions, it becomes possible to derive the average future annual production of a group of wells, their generalized decline curve and the average life of the group. For example, a well in the Osage Reservation, producing 110 bbl. daily, or about 40,000 bbl. during its first year, according to Fig. 4, has an estimated total (or ultimate) production of 87,000 bbl. and hence a future of 47,000 bbl. Reversing the process and reading from 47,000 bbl. on the right margin of Fig. 4 to the left where the average total production curve is intersected, we find that a well with a future production of 47,000 bbl. must, the first year, produce on the average about 15,300 bbl. This amount deducted from 47,000 bbl. leaves a future of 31,700 bbl. which in turn is the ultimate production of a well producing about 8800 bbl. the first year, and so on. These calculations may be continued until the original 87,000 bbl. is extinguished, which should occur at the time the estimated production has declined to 1 bbl. per well day, which is the assumed minimum daily production to which Osage wells can be profitably pumped. The yearly production of the generalized production curve thus derived reads 40,000, 15,300, and 8800 bbl. for the first 3 years, respectively.

Theory of Generalized Curves Showing the Decline in Production

Fig. 9 represents the maximum, average, and minimum types of production curves for oil wells in the eastern part of the Osage Reserva-

tion. These curves were derived from Fig. 4 by computing from the largest wells recorded their generalized maximum, average, and minimum production curves from the total production curve on Fig. 4 in the manner just described. Wells whose production curves follow along or near the minimum curve (Fig. 9) are wells with sharp declines and small cumulative percentages, whereas production curves of wells following the maximum curve are of the opposite character. Production curves of other wells would be intermediate but, regardless of the amounts of their production, should follow systematically within the extremes and should fall into similar positions, as do their cumulative percentages in Fig. 4.

To estimate the decline for a well or a group of wells, the first year's production may be plotted on the average decline curve (Fig. 9) at its intersection with the line indicating that production, disregarding the time periods. The annual productions for each of the following years are then plotted at intervals representing time periods of one year each. If the later points deviate from the average decline curve, the well is not an average well. If continued for a number of years, its curve will diverge from the average and tend to follow or parallel the type of curve to which it belongs. The point of beginning may be shifted from the average curve till the record lies symmetrically between the average and one extreme. This may be more conveniently found by plotting the record on transparent paper and superposing it over the generalized type curves.

In Fig. 9, the production records of seven of the 68 properties in the Osage Reservation are shown by different symbols plotted on the generalized decline curves. These selected properties represent wells of different sizes and types. The properties plotted along the maximum decline curve in Fig. 9, were properties whose cumulative percentages fell along the maximum in the appraisal curve (Fig. 4) and those following the other two curves held similar positions in the appraisal curves. It is to be noted how closely the actual productions of each property follows the estimated productions of its type on the generalized curve. Had the operator been able to forecast the future production of his wells from the first year's production, he would have had in advance an excellent idea of the future annual production of his properties. As may be expected, however, the actual production curves are always more or less unsymmetrical and may fall above or below the expected production for a particular year, yet those examined in the Mid-Continent field were on the whole surprisingly symmetrical, considering that, as in the Osage curves, the development had not been regular and the wells had been "shot" or the conditions otherwise changed in such manner as to effect the productions of the wells.

When records for several years are not available, the well may be assumed to be an average well and the future forecasted on that basis with the same probabilities of inaccuracy as in using Fig. 4. If the

monthly production is recorded,[5] these data can be used in the same manner as for years, being plotted at spacings $\frac{1}{12}$ that for years, and upon determination of the character of the curve, the future can be projected. Similarly, any period, such as quarter-, half-years, or periods of two or more years, may be used as the time unit. For convenience, the curves in Fig. 9 have been plotted on two scales from the second year on.

It is to be noted that wells of entirely different initial sizes may follow curves of the same type and that the curve of a small well may be overlapped by the end of the curve of a large well. This is the logical conclusion to be derived from the proof submitted in Fig. 7 and 8, that wells of equal output on the average have practically the same future production regardless of their ages. All properties on the minimum appraisal curves of Fig. 4 tend to follow the generalized minimum decline curve (Fig. 9) and the other properties fall into positions on the other generalized curves similar to those indicated by their cumulative percentages in Fig. 4. An excellent example is shown in the three properties following the minimum decline curve (Fig. 9), one beginning at 177 bbl., another at 55 bbl., and the third at 21 bbl., which were their average daily productions during their initial years. These and the other curves following as closely as they do the theoretical curves, confirm the fact that wells of equal size have approximately equal future production regardless of the ages of the wells.

Based on these last facts, generalized decline curves can be constructed by taking the decline curves of those properties lying along the three cumulative percentage curves in Fig. 4 and 5, beginning with the largest wells, and starting the next largest on the curve of the first where it reaches the production of the second well's initial year. In this way, if enough wells fall along the three curves and if wells of different sizes for the three types of decline curves are represented in Fig. 4 and 5, the same generalized decline curves may be derived. Logarithmic coördinate paper will be found useful for this purpose.

From the nature of the generalized decline curves, the reasons are apparent why we chose to present them as maximum, average, and minimum curves instead of as one general average curve starting at 100 per cent. and declining in percentages thereafter, as in Fig. 1, 2, and 3 respectively. Such generalized average curves have been constructed and used, particularly in California, with a total disregard of the fact that large and small wells decline at different rates. Where sufficient data are available, much closer estimates of future production

[5] If monthly productions are used, however, especially in a field like the California field, it is necessary to take into consideration all the factors that tend to reduce the productive days of a well, such as cleaning out, etc.

can be made by constructing the different types of curves for different initial production, as well as for the different conditions affecting the productivity of a well.

As has been pointed out, the production of wells in practice varies from the ideal curves because of the many ways in which changing conditions may affect the production of the wells. Some Osage curves showed greater variations than those plotted in Fig. 9, but all indicated a marked inclination to approach the ideal curve they were following, though some would suddenly deviate from one and from there on follow another.

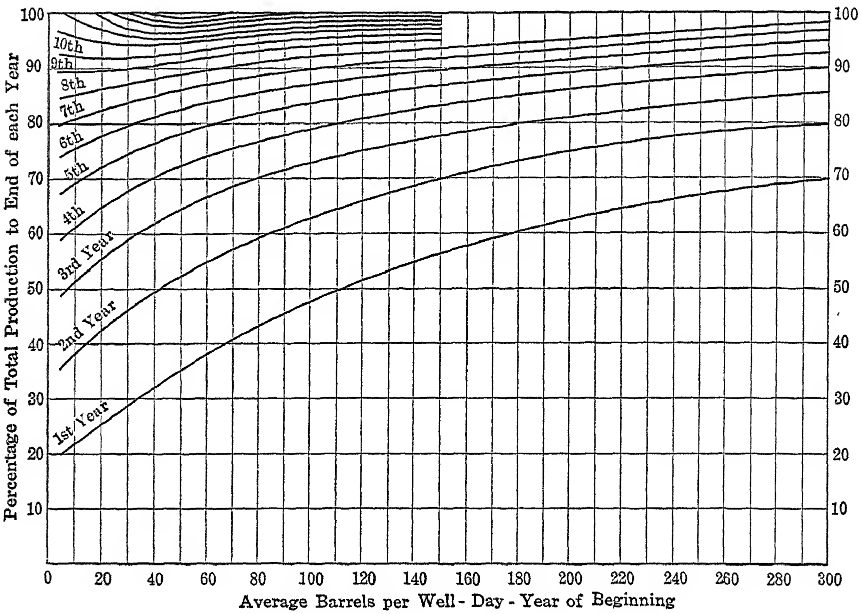


FIG. 10.—CHART SHOWING PERCENTAGES OF ULTIMATE PRODUCTION OBTAINED TO END OF EACH YEAR FOR WELLS IN THE OSAGE RESERVATION WHICH FOLLOW THE GENERALIZED PRODUCTION CURVE.

These variations are not without cause, and if all the facts regarding the wells were available, reasons for many deviations from the generalized curves could doubtless be found. Studying of the effect on production of various factors affecting wells, by notation of deviations from the generalized curves, is believed to offer a very promising field of useful investigations on the production of oil, for it would not only aid in forecasting future productions but would help the producer to judge the efficiency of his production methods.

Knowledge of these irregularities in well production has discouraged efforts in devising methods for estimating future production and has given the producer little faith in the possibilities of such methods. From

our experience, however, the outlook is believed to be more encouraging and a greater proportion of the curves follow regular declines than has been supposed. We are also hopeful that extended investigations will permit still closer and more trustworthy estimates of the future production of practically any sort of well excepting those few of a very freakish nature.

In appraising a property or in estimating the depletion charges that should be made on a company's books, it is desirable to have an estimate of the percentage of the total production that will be obtained to the end of each year. Fig. 10 illustrates a graphical method for presenting such information. It is derived from the ideal curve (Fig. 9) for an average well in the Osage and can only be used on wells following this type; for other curves, other charts would have to be prepared. The figure shows that the proportion of the total production obtained the first year is greatest for the largest wells, which is the logical result expected from Fig. 4, 5 and 9.

Suggested Methods for Making Closer Estimates

While the methods outlined in the foregoing pages have proved of much value in estimating future productions, refinements are desirable that will more closely define the probabilities of wells, at earlier periods in their lives and with fewer data. The variations in the ultimate production of wells of equal initial output are not without cause, and systematic study in the manner of the development of Fig. 4 and 5, and of the various factors influencing production, should result in ways of narrowing the limits of future production over those defined by comparing the initial production against total production, and thus make estimates more accurate. Moreover, closer study may permit the use of curves derived from the data of one field to be applied with more confidence to another field newly developed by noting the differences and how they affect the future production of wells. The difference between the curves derived from wells of the Osage Reservation and those from the Nowata Field have been noted. In the latter field some of the conditions, such as original gas pressure, were more uniform, and hence the narrower limits, and the consequently greater accuracy with which the future productions could be forecasted, were not unexpected. Comparisons of fields and properties in relation to such factors as gas pressure should result in providing bases for estimating the comparative effect of gas pressure and other influences. The appraisal curves for the Osage district and for the Nowata Field were derived by plotting the total production of individual wells against their production for the first year. Some of the other factors against which the total productions could be plotted are gas pressure, thickness of oil sands, or "pay," character of

oil sands, quality of oil, etc. These are all natural conditions, but, in addition, the spacing of wells, "shooting," perforations, manner of operation, use of stimulating methods such as gas pumping, etc., could be profitably studied.

Upon assembling sufficient data, it might be found that a 20-bbl. well of a certain gas pressure in the Osage would nearly always be above the average, or if the wells were spaced a certain distance apart, the tendency would be above or below the average for wells of that size. It will doubtless be found that while some factors are of much importance others are only of slight influence and may be neglected. The fact must not be lost sight of, however, that the trend of the production curve is determined by the composite influences of several factors rather than that of one. Some of the factors may be found to be of importance, but are so seldom recorded that they will be of little use in practice. Study will not only bring out the values for the various factors, but indicate what records should be kept by the producer who desires to have the worth of his property estimated.

It may be contended that natural vagaries of the wells—water troubles, economic conditions, changes in the manner of operation, etc., are things which cannot be forecasted, thus making attempts at close estimates hopeless. It is our opinion, based on study and experience, that the behavior of wells throughout their lives is more intimately controlled by conditions established early in the life of the wells than has been supposed. Also, that careful systematic study will disclose methods permitting unexpectedly close estimates. All uncertainty, of course, can never be eliminated, nor can absolutely accurate calculations be made on account of minor unforeseen influences and occasional conditions arising which cut short the life of a well. Furthermore, there is always the possibility that the development of methods for increasing the recovery of oil, like the Smith-Dunn compressed air process, may radically change the quantity of oil recovered from a property.

Use of Logarithmic Coördinate Paper

In the study of production curves and in the development of the methods discussed in this paper, logarithmic coördinate paper, such as was used in Fig. 11, has been found to be of particular value, and the writers believe it will eventually prove to be very useful in studying production-curve problems. The purpose here is only to suggest the use of logarithmic paper and to point out a few of it's advantages. For the general use of such paper, the reader is referred to any standard work covering the subject.

An equation of the form $y = cx^n$, when plotted on logarithmic paper, will be represented by a straight line whose slope is n. It has

been found that many production records of individual wells and many composite production curves from different parts of the country can be made to approach straight lines when plotted on logarithmic paper. For example, Fig. 11 represents the percentage decline in the average production per well on 34 properties in a West Virginia field. Apparently the general tendency is for production curves to approach straight lines with different slopes and different points of origin in accordance with their particular type.

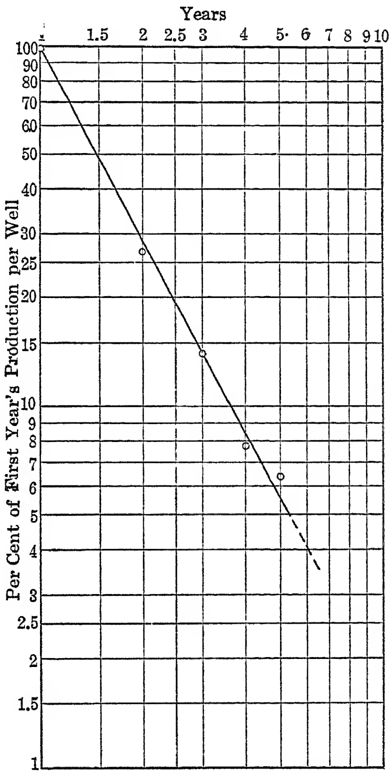


FIG. 11.—AVERAGE DECLINE PRODUCTION CURVE FOR WELLS ON 34 PROPERTIES IN A WEST VIRGINIA FIELD, PLOTTED ON LOGARITHMIC COÖRDINATE PAPER.

The advantage of being able to reduce a curve to a straight line is obvious, for its projection becomes simple and accurate. Moreover in the later life of the well, when productions become very small compared to the earlier productions, the curve is projected on the logarithmic paper into an area where the scale is larger and hence more easily read. The effect of various factors on the production curve can also be traced more clearly as they deviate from a straight line. From logarithmic paper, many short cuts can be figured and it becomes possible to reduce the curves to their equations more readily, if this is desired.

Summary

In this paper the following points have been brought out:

1. The usefulness of percentage decline curves and particularly of cumulative percentage curves.
2. Demonstrations that systematic relations exist between the initial output of wells, their total cumulative percentages, and their total productions.
3. That these relations vary for different fields and conditions.
4. How these relations may be shown graphically in so-called "appraisal curves" from which rapid estimates may be made of the future production of wells in a certain district.
5. By this method the extremes as well as the averages are known so that the probable limits of error may be estimated.
6. Appraisal curves for the Osage and Nowata districts in Oklahoma are given.
7. Demonstrations are given showing that, on the average, wells of equal yield will have approximately the same future productions, regardless of the ages of the wells.
8. How generalized decline curves may be derived that show both the average and extreme curves for wells of various sizes in a certain district from which the future decline curves of wells in the same district may be estimated.
9. An analysis of the factors influencing the productivity of wells and their decline curves.
10. The extent to which previous development may influence the initial productions of later wells.
11. A graphical method for showing the relative depletion of wells of different sizes throughout their lives.
12. How the methods outlined may be developed further to make them more accurate and useful.
13. Some advantages of logarithmic coördinate paper in estimating future production of oil wells.

DISCUSSION

Roswell H. Johnson,* Pittsburgh, Pa.—The petroleum industry has suffered very severely from the lack of just such work as has been done by Messrs. Beal and Lewis. I think we owe a great deal to the Bureau of Mines for at last undertaking this much needed work, even though it is so belated. It could have been of very great assistance in so many properties where its usefulness has now passed.

I think it is perhaps well to sound a note of caution, owing to the fact

* Johnson & Huntley, Pittsburgh, Pa.

that so much of this information was derived from eastern Oklahoma; but with the promised new bulletin giving the decline for many fields, there will be far less danger of falling into error through assuming too much uniformity. The cumulative percentage curve seems to me to be a particularly splendid idea. It should have a very important influence, especially as the authors have themselves pointed out several variables that ought to be taken into consideration. The thickness of the pay, I think, is going to be an especially important one to work out along the general lines of method that they have advanced.

Probably the most surprising thing in the paper is the general rule that the decline of a well is more correlated with its size than with its age. I can't help but think that that generalization, important as it is, is limited and will not apply so clearly when we have a larger number of fields before us. Still the generalization, rough as it is, is of very great importance, since the industry has been basing a great many of its practices on the opposed principle that decline rate is mainly a matter of age.

It leads to certain corollaries that are of great consequence. The first is that the undrilled portion of the property must be appraised on a different basis from that used for the drilled portion.

Now when we find, as shown in the paper, that in Glenn Pool the recoverable oil per acre is vastly less in the parts that were drilled late, as compared with the earlier parts, it shows how very dangerous it is to take a property that is half drilled-up, and take acreage production data from the drilled-up part and apply that to the undrilled part. It seems to me very important that appraisers should make a decided distinction between drilled portion and undrilled portion, and the degree of this distinction should depend upon what proportion of the original gas pressure has been depleted. We are not measuring gas pressure as much as we ought to in appraising pools. In that connection, I think Healdton is interesting. Wells there are larger in proportion to their very low pressure, than in most pools. From this, we may predict a slower decline than is true in most pools.

The next corollary is the very great danger of the barrel-day price method. That method is based on the hypothesis that the rate of decline is independent of size and of age after about the first year. I have already called attention to the danger of that rule from a different standpoint, but this again brings out that danger. Now it is true, of course, that appraisers must have some handy rules, and it is an absolute necessity to be able to make up one's mind quickly, and it is in this need for rapid-fire appraisal that the barrel-day method has come in, faulty as it is. I think one of the things that we need to do, after having elaborated on a thoroughly good appraisal method, is to turn our attention to some methods that will not be too erroneous and yet permit more rapid work. Both in the companies and in private practice, it frequently happens that

we cannot make an appraisal in the way in which it should be done, and yet a judgment must be quickly reached. I shall present at the next meeting a device by which a factor consisting of the ratio of past to future production is used for this purpose.

There is a third corollary of that general law, that I want to mention. It follows that the influence of gravity in flowing the oil into the hole must be very much less important than the expulsion by the gas. This expulsion is caused by the gas which comes out of a solution in the oil and accumulates as small bubbles of gas throughout the sand, as well as in the main body of gas that may be at some distance away from the well. Obviously the thickness of the sand would be so great a factor as to have made Beal's rule of size impossible, if it were just the flow of gravity that accomplished the result. It must be that the thicker sands are relatively penalized by the fact that their gas pressure goes down faster because there is a better chance for the gas to by-pass the oil at the top of the sand.

This paper will do much to prevent some of the current misconceptions of the production curve of wells. It points out some methods which we may hope will stimulate the publication of similar needed studies from various fields. One of the important results will be the aid in placing the financing companies on a very much sounder basis.

Eugene Wesley Shaw,* Washington, D. C. (written discussion†).—Studies of the probable future production of oil wells and fields—particularly those in the nature of the recent work by Lewis and Beal, having the object of increasing the percentage of recovery—rank, in both practical and theoretic value, very high, if indeed they do not outrank all other petroleum investigations except structural surveys. Even such surveys, although saving untold millions that might have been spent in prospecting unpromising territory, may have less ultimate value than generally supposed, for it may perhaps be argued that much if not most of the condemned territory will sooner or later be tested—some is already productive—and the most that can be rightly claimed is the recovery of cream first; also that the consumption of the richest portions first cannot be extenuated, as it might with some resources, on the ground that if the best is not taken now it will deteriorate.

On the other hand, he who can raise the fraction of petroleum recovery by 1 per cent. has added millions to our national resources, just as he does who saves oil from fire, the only difference being that possibly the oil left in the ground may, in a century or two, collect and form a new pool.

I had the opportunity of reading the present paper by Lewis and Beal

* Geologist. U. S. Geological Survey.

† Received Apr. 1, 1918.

in manuscript, and I felt that I should like to see performance records of individual representative wells. Unfortunately, such records seem not to have been kept in the Osage and Nowata fields, which furnish most of the foundation of this paper. Although some of the relations set forth seem sufficiently obvious to need no corroborative data, it seems to me that for both scientific and economic reasons it is highly desirable to record the monthly yields of individual wells and, until a good sized available supply of such data is accumulated, to publish the details. Some readers will, without failing to appreciate the personal backing of the conclusions, wish to know the precise nature of the foundation and to have the data for further analysis.

The so-called saturation or pore-space method of estimating unrecovered oil is not, it seems to me, of such small value as Lewis and Beal and others believe. I have used it with satisfactory results in a number of fields, and believe that, with recognition of its limitations, it has a good deal of value, particularly where standard tools are used, and fairly accurate information can be gained concerning not only the thickness and lateral extent of the pay, but water and "dry" streaks in the pay, size of pores, and also methods of recovery. Where, because of lack of recorded data, or for any other reason, other methods are inapplicable, the pore-space method commonly gives results that, I believe, are far better than none at all, and elsewhere it can be used as a valuable side light, corroborating or throwing doubt, as the case may be.

Fig. 4 and 5 of the paper are of much interest and worth careful study. In the first place, it seems to me that, unless the relations are clearly indicated, it is somewhat confusing to find two sets of curves with different scales plotted on the same area, the scale for one being shown on one side and for the other on the opposite side of the diagram. Also, the words "per well" seem to be needed after "total production."

Certain facts lead one to ask, Just how well established are the form and position of the curves in Fig. 4 and 5? These facts are that the position of the points is to a degree inferential (the extent not being apparent) because some of the properties are presumably still producing, so that their ultimate yield is a matter of estimate; that some of the points plotted fall outside the area between the maximum and minimum curves; that the statement is made on page 508 that "judgment must be used in selecting and applying the records;" that the two curves approach each other in the direction that the observed data become less numerous, and in the direction of increase in per cent. of past production as compared with total production; and that the dots do not become much more numerous toward the average curve.

It should be borne in mind that the curves are sketched, and hence that two persons would not draw them just alike. It is evident, also, that a field of small extent and uniform conditions, even though divided into

many properties, will give a denser pattern of dots than a large field of various and varying sands and other irregularities. Also, a field each of whose properties is quickly drilled up will give a different diagram from one where the leases are only gradually drilled.

Concerning the general features of the diagrams and the conclusions drawn from them, there can be little doubt, but for the general application of the method there appear to be certain necessary conditions which can not always be met. There would seem to be the following requisites for using the curves in estimating future production: (1) The field should be well along in development, and production records of many properties should be available, so that the curves can be constructed; (2) the property in question should be a year old—and that means that it has produced from one-fifth to two-thirds of all that it will ever produce—so that its position on the diagram can be plotted; (3) recognition of the probable error.

This probable error is really quite large, especially for wells of small initial production, perhaps because a smaller fraction of the total production of such wells is yielded the first year. If one has a drilled-up lease in the Osage that has been producing a year at an average rate of 10 bbl. per well per day, or 3650 bbl. per well for the year, he may expect to get in the future from 1.6 to 5.8 times as much—a rather wide range of possibilities—the best guess or mean being 3.2 times. It will be noted that 3.2 is below the arithmetic mean of the two extremes, and from the figure it will be seen that it is considerably below the algebraic sum of the points plotted above and below the mean. If his wells have averaged 100 bbl. a day for a year, instead of 10 bbl., the quantity that he may expect still to recover will be 1.2 times what the lease has already yielded, but he may get as little as 0.6 or as much as 2.1 times the past production.

The question naturally arises, How much better are these estimates than the guesses of experienced operators? Could not almost any good oil man make, at the end of a year of production of one of his leases, a guess at the future production of that lease which, barring accidents and unusual features, as is done with the "appraisal curve" method, could be depended upon as being not many fold in error? And if the wells had averaged large, so that a larger fraction of the ultimate output had already been produced, might not his guess be accordingly close to the true figure?

Qualitatively, the diagrams of Lewis and Beal have certainly a twofold value. For men of lesser experience they tend to make it possible to estimate future production, presenting in concrete, available from the data concerning two fields, and they make available a new method of attack for other fields where there are enough recorded data. Second, for men of greater experience, they furnish material for better estimates and a better understanding of the probable error.

Apparently the practical oil producer, who makes estimates without itemizing the basis in detail, has the advantage in two respects; he can use the details in the rate of decline of the property, and, if it has been producing for more than a year, he can use the more nearly complete record of production. Also, he may be acquainted with idiosyncracies of individual wells that tend properly to modify estimates of future production. As noted above, the larger the fraction that has already been produced, the better the estimate of future production by whatever method.

Perhaps the most striking conclusion of the paper is that "wells of equal yield will have approximately the same future productions regardless of the ages of the wells" (page 520). This seems to be in disagreement with the individual well curves and conclusions presented in Mr. Requa's paper (This volume, pp. 526–545), with production curves of wells in other fields so far as recorded, with the general impression that has given rise to the expression "settled production," and with theoretical considerations concerning the performance of a well yielding a liquid and a gas from the pores of a sand where they have been under high pressure. One wonders, therefore, if a similar conclusion would have seemed justifiable if records of individual wells had been available. In other words, if it does not depend upon the overlapping of individual curves in the group or property curve, thus tending to reduce the steepness of the usually sharp initial decline. With the exception of wells that produce from unconsolidated sands, of which the production commonly increases for a time, the general rule is surely beyond question that the yield of a well falls off more rapidly at first, not only in number of barrels but in per cent., than it does later. The records of individual performance that are available to me come from several widely separated fields, and do not seem to bear out either the conclusion of Lewis and Beal that future production is independent of age but depends wholly on present production, nor that of Requa that the ultimate production varies directly as the initial production.

Methods of Valuing Oil Lands

BY M. L. REQUA,* SAN FRANCISCO, CAL.

(New York Meeting, February, 1918)

THIS paper is abstracted from the report of the Appraisement Committee of the Independent Oil Producers' Agency, of which the writer was Chairman. The other members of the committee were M. V. McQuigg and R. S. Haseltine. To Thomas Cox, engineer in charge of the investigation, and to his efficient staff of assistants, is due the credit for the detail work necessary in carrying out the plan of the Committee. It treats only of the valuation of the lands, wells, and piping, without going into details of equipment and other features.

It was recognized, early in the operation, that the value of oil lands was the value of oil to be extracted and marketed, less the costs attendant thereon. Referring this back to the costs in cents per barrel, it became obvious that surface improvements, absolutely necessary in the production of oil, from wells then drilled, had no separate and independent value aside from the value of the land, but that any excess equipment, not necessary for the production of oil from present wells, such as drilling tools, well casing, etc., should be given a present condition value.

In valuing the properties of the Independent Oil Producers' Agency, the Committee has considered the following facts:

1. That from each property there will ultimately be produced a certain total quantity of oil.
2. That in the production of that oil a certain total quantity of money will be expended.
3. That a certain total amount of money will be received from the oil.
4. That the total net receipts will be the total gross receipts less the cost of development and production.
5. That the present value of the net receipts must be such an amount that when invested by a purchaser it will be returned with 8 per cent. interest additional during the life of the property.

The initial procedure consisted in making a general reconnaissance of the entire district in which the property was located and determining the lithological and structural conditions underlying the area. The data obtained from each individual tract comprised the logs of all the wells

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with the history of each individual well wherever it was possible to obtain it, also the total production from the property and from each well whenever such data were available. It was also necessary to make a complete inventory of all the surface equipment and estimate its present worth.

The next step consists in collecting enough production data to construct a curve for each district, showing the decline of an ideal well from its inception to its exhaustion. This was accomplished by obtaining all available information regarding the total yearly production for individual wells in each area and compiling it so that the average curve would be a compilation of the first year's production of all the wells, the second

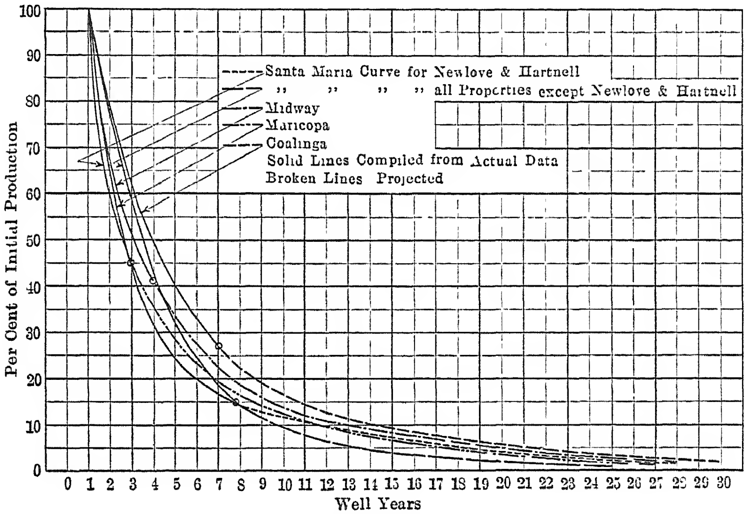

FIG. 1.—PRODUCTION CURVES.

With these curves there is a certain volumetric content This is used to estimate the total production of one well during its life by multiplying the initial production of the new well by 365 days, and by the figure shown as the volumetric content, which will give the number of barrels the well will produce to the 1-bbl -per-day point of cut off, For example, on the Coalinga curve the volumetric content is 5 738 A 50-bbl well would produce 50 by 365 by 5 738, which equals 104,718 bbl.

The other volumetric contents are as follows:

Kern river	5.5
Maricopa	4 452
Midway	4 976
McKittrick	5.738
Santa Maria (Except N & H)	4 3805
Santa Maria	4 2730
Fullerton	5 738

year would be a compilation of the second year's production of all the wells, and so on through the past years to date. These data computed on a percentage basis showed a constantly lessening decrement and this decrement was computed for the succeeding years. The results of the compilation of the data in each field are shown graphically in Fig. 1.

In the Coalinga field the monthly production of 86 individual wells was obtainable over a period of 7 years. These data were arranged so that the resultant curve shown on Fig. 1 was a compilation of the first

Data for Well Curves—Coalinga Field

	Well No.	1st Year	2d Year	3d Year	4th Year	5th Year	6th Year
Company A, Section 18	1	......	20,994	19,797	13,967	11,903	
	2	......	40,378	36,822	17,450	13,273	
	3	......	29,860	49,669	25,125	20,891	
	4	......	51,570	38,532	27,232	25,506	
	5	56,267	37,385	30,359	23,022	15,141	
	6	70,445	69,020	45,317	33,899	20,098	
	7	21,095	17,660	11,780	10,569	5,602	
	8	30,760	58,020	28,428	2,107	2,793	
	32	64,984	103,117	68,309	57,104	29,925	
Total barrels		243,551	428,004	329,013	210,475	145,132	
Number days		1,825	3,285	3,285	3,285	2,490	
Average barrels per day	...	133.4	130 3	100.1	64.1	58.2	
Company A, Section 6	7	21,092	22,380	15,201	9,297		
	10	19,467	33,342	20,021	7,724		
	14	64,274	69,986	18,942	3,855		
	19	52,246	48,103	50,262	8,408		
Total barrels		157,079	173,811	104,426	29,284		
Number days		1,460	1,460	1,460	605		
Average barrels per day		107.5	119 1	71 5	48.4		
Company A, Section 30	1	......	96,455	28,910	31,720	19,781	11,658
	2	......	84,555	54,733	53,093	24,570	15,348
	3	......	77,370	46,548	37,089	30,817	6,777
	4	......	87,046	51,197	48,890	30,201	7,180
	5	......	76,490	47,477	8,183	25,582	5,273
	6	.....	114,880	52,000	61,540	44,984	17,532
	7	112,285	139,100	66,095	15,953	19,721	
	9	265,945	118,503	94,497	82,429	7,640	
	10	53,310	62,429	73,346	48,754		
	13	59,230	36,929	35,564	31,736	19,750	
	22	71,123	51,555	42,717	2,512		
	23	56,040	30,471	15,869			
Total barrels		617,933	975,783	608,953	421,899	223,046	63,768
Number days		2,190	4,380	4,380	3,680	2,585	910
Average barrels per day		282.0	222.5	139 0	114.6	86.4	70 0
Company A, Section N-30	1	52,220	36,396	15,182	14,090	3,688	
	3	141,130	40,625	29,913	14,828	6,335	
	6	17,775	46,616	63,502	68,344	15,680	
	7	64,310	49,267	36,852	6,065		
	8	60,105	29,883	22,841	4,593		
	10	35,032	18,601	8,226			
Total barrels		370,572	221,388	176,516	107,920	25,703	
Number days	....	2,190	2,190	2,125	1,790	425	
Average barrels per day	....	169.0	100.9	83.1	60.2	60.4	
Company A, Section 19	1	138,590	46,525	25,669	5,619	3,610	
	3	35,875	38,995	16,715	8,104	5,593	
	5	93,700	43,437	33,361	30,440	7,239	
	8	91,630	25,395	27,063	19,761	9,825	
	16	103,035	75,276	24,545	33,662	17,035	
Total barrels	....	462,830	229,628	127,353	97,586	43,302	
Number days	....	1,825	1,825	1,825	1,825	910	
Average barrels per day	....	253.0	125.8	69.8	53 5	47.6	
Company B, Section 30	1	97,962	56,158	41,202	23,797	8,178	
	2	31,534	23,188	15,503	23,095	6,956	
	3	104,248	40,479	40,250	33,135		
	4	49,493	42,579	32,921	10,445	2,630	
	6	156,293	96,418	13,298	7,880		
	8	65,111	43,169	46,181	32,385		
	2–A	38,995	13,536	28,840	12,010		
	4–A	60,692	47,043	42,300	9,265		
	5–A	13,132	35,837	29,060	3,390		
	6–A	18,157	20,800	19,845	2,885		
	7–A	41,327	37,294	9,060			
	8–A	68,795	46,171	51,240	1,655		
	1–B	70,544	44,565	37,440			
Total barrels	....	816,283	547,237	407,140	159,942	17,764	
Number days	....	4,745	4,745	4,590	2,555	425	
Average barrels per day	....	172.2	115.2	88.8	62.6	41.8	

Data for Well Curves—Coalinga Field.—(Continued)

	Well No	1st Year	2d Year	3d Year	4th Year	5th Year	6th Year
Company B, Sec. 18.......	1	43,694	48,117	42,609	20,948	10,159	
	2	126,294	41,215	22,743	18,100		
	3	58,557	51,353	25,521	11,085		
	4	76,085	57,131	42,960	22,095		
	1–A	29,849	12,795	9,805			
	2–A	19,583	13,357	9,290			
	4–A	63,324	46,501	30,345	2,800		
	5–A	59,283	45,623	40,205			
	5–B	48,657	40,265	18,310			
	5–D	50,171	31,260	4,735			
Total barrels........		575,497	387,617	246,523	75,028	10,159	
Number days		3,650	3,650	2,980	1,215	180	
Average barrels per day........ .	...	152 5	106 1	82 8	61.6	56.6	

Data for Well Curves

Coalinga Field

	1st Year	2d Year	3d Year	4th Year	5th Year	6th Year	7th Year
Company C,.................	25,994	14,628	12,049	9,625			
Number of days............	365	365	365				
Average barrels per day	71.2	40.1	33.1	26.4			
Grand total of above figures .	3,269,729	2,978,186	2,012,032	1,111,759	465,106	63,768	
Grand total number days.....	18,250	21,900	21,010	15,320	7,015	910	
Grand average barrels per day.	179.0	135.8	95.7	72.5	66.3	70.1	
59 wells....................	100.0	75.8	53.5	40.6	33.3		
	Applied to Curve						
Totals of sheet No. 1.	100.0	75 8	53.5	40.6	33.3		
Totals of sheet No. 2..........	100.0	83.6	69.6	58.0	47.7	39.1	31.8
Mean.......................	100.0	79.7	61.5	49.3	40.5	33.0	27.1

years, the second years, etc., of all the wells according to the method previously stated.

As the Kern field is one of the oldest in the State and yearly production records were poorly kept, accurate data concerning its early history were not obtainable. It was found impossible to compile any data that would substantiate the results in Coalinga, but as the number of wells to be drilled was very small in comparison with the total productive area, and as the conditions regarding production approximate those in Coalinga field, it was decided to use the theoretical figures of the Coalinga curve in computing the production from new wells in this area.

In constructing a curve for new wells in the Maricopa district, the individual records of 29 wells were obtainable and these figures were used to construct a curve by the same method as was applied in Coalinga. In the Midway district the yearly production records were obtainable from 24 wells and a curve constructed from these data. In two instances where flowing-well conditions existed, special curves were developed from records of wells in similar territory.

Coalinga Field

PRODUCTION CURVE

Year	Per Cent Value of Previous Year	True Curve Figures	Results of Data as Platted	Year
1	....	100.00	100.00	1
2	100.00 × 78	78.00	79.70	2
3	78.00 × 79	61.60	61.55	3
4	61.60 × 80	49.30	49.30	4
5	49.30 × 81	39.93	40.50	5
6	39.93 × 82	32.64	33.00	6
7	32.64 × 83	27.10	27.10	7
8	27.10 × 84	....	22.70	8
9	22.70 × 85	....	19.40	9
10	19.40 × 86	....	16.60	10
11	16.60 × 87	....	14.45	11
12	14.45 × 88	....	12.75	12
13	12.75 × 89	....	11.35	13
14	11.35 × 90	....	10.20	14
15	10.20 × 90	....	9.20	15
16	9.20 × 90	....	8.30	16
17	8.30 × 90	....	7.50	17
18	7.50 × 90	....	6.70	18
19	6.70 × 90	....	6.00	19
20	6.00 × 90	....	5.40	20
21	5.40 × 90	....	4.90	21
22	4.90 × 90	....	4.40	22
23	4.40 × 90	....	4.00	23
24	4.00 × 90	....	3.60	24
25	3.60 × 90	....	3.20	25
26	3.20 × 90	....	2.90	26
27	2.90 × 90	....	2.60	27
28	2.60 × 90	....	2.30	28
29	2.30 × 90	....	2.10	29
30	2.10 × 90	....	1.90	30

In the McKittrick field no data were available that could be used to construct a curve for an ideal well, and as the general conditions compared favorably with the Coalinga field, the Coalinga curve was used for this field.

In the Santa Maria field the individual well production was obtainable from every well which the Union Oil Co. drilled, and as some of the wells have been producing for 10 or 11 years, excellent data were available. These were divided into two types and two individual curves constructed.

Company D.

YEARLY PRODUCTION OF WELLS

Well No.	Days	Years 1	Days	Years 2	Days	Years 3	Days	Years 4	Days	Years 5	Days	Years 6	Days	Years 7
4	......	×	......	......	330	16,964	365	10,606	365	10,308	365	9,798	365	5,434
9	......	×	......	30,744	365	26,752	365	20,888	365	19,104	365	13,364	245	7,411
10	......	×	......	25,073	365	18,536	365	13,325	365	11,265	365	7,920	212	2,558
11	......	×	......	27,329	365	15,577	365	14,252	365	13,236	365	9,733	212	3,870
12	......	×	......	32,331	365	27,770	365	18,898	365	17,426	365	5,665		
13	......	×	......	13,366	365	15,760	365	25,750	365	22,223	365	15,516	125	4,755
14	......	×	......	13,445	365	15,421	365	16,111	365	10,355	365	7,659	120	2,874
15	......	×	......	24,762	365	24,482	365	18,878	365	17,141	365	12,960	91	2,861
16	335	12,966	365	15,135	365	15,992	365	10,180	365	8,279				
17	345	19,469	365	18,650	365	23,970	365	25,132	365	14,947	365	9,821		
18	350	26,961	365	31,210	365	12,686	365	9,187						
19	300	20,384	365	26,020	365	15,509	365	13,322	365	7,562	365	5,954		
20	300	39,773	365	38,091	365	15,497	365	14,420	365	11,009	365	9,315		
21	365	38,171	365	38,501	365	30,565	365	21,988	365	15,589	365	7,506		
22	365	24,864	365	18,000	365	12,554	365	10,756	210	4,686				
24	350	23,149	365	28,107	365	12,227	365	7,329	60	1,403				
26	365	23,370	365	19,572	365	23,129	365	19,082	365	16,468	305	11,962		
27	......	×	365	33,669	365	26,508	365	15,669	150	7,044				
28	365	16,130	365	11,026	365	10,302	365	6,810						
29	365	18,206	365	17,746	365	12,099	305	7,519						
30	365	23,630	365	17,200	365	11,416	275	6,948						
31	365	25,340	365	12,202	365	6,409	61	702						
32	365	16,760	365	13,047	365	10,188								
33	365	24,174	365	12,467	270	5,851								
34	365	16,455	365	12,444	180	6,865								
35	365	28,039	365	15,228	300	8,380								
36	365	31,591	365	19,664	365	10,365	120	3,417						
37	365	21,805	365	12,493	365	8,838	180	3,635						
Total barrels	......	451,237	......	577,522	......	440,610	......	314,904		208,045		127,173		29,763
Time, days	6,525	......	9,855	......	9,840	......	7,876	......	5,530	......	4,685	......	1,370	
Average per day, barrels, actual	......	69.0	......	57.7	......	45.0	......	40.0	......	36.0	......	27.0	......	21.7
Average per day, barrels, corrected	......	69.0	......	57.7	......	48.0	......	40.0	......	33.0	......	27.0	......	21.7
Percentage	......	100.0	......	83.6	......	69.6	......	58.0	......	47.7	......	39.1	......	31.8

× Incomplete.

Santa Maria and Lompoc Oil Fields

COMPILATION OF AVERAGE DECLINE OF NET PRODUCTION OF ONE WELL

Property	Well No.	1st Year	2d Year	3d Year	4th Year	5th Year	6th Year	7th Year	8th Year	9th Year	10th Year
Santa Maria field;											
All properties, 35 wells	.....	5,513,256	3,714,207	2,403,427	1,733,133	1,329,968	1,069,125	760,573	448,950*		
Average product, well days	.....	431.6	290.7	188.1	135 6	104.1	83.7	59.5	33.5		
Actual per cent. decrease, per cent. I. P.	.....	100 0	67.3	43.6	31.4	24.1	19.4	13 8	12 4		
Adjusted per cent. decrease	.....	100.0	67.3	43.6	31.4	24.1	17 6	13.8	12.4		
S. M field excluding Newlove and Hartnell, 24 wells	.....	3,471,820	2,934,383	2,048,728	1,461,741	1,101,258	850,577	545,065	350,640**		
Average product, well days	.....	396 3	335.0	233.9	166 9	125.7	97.1	62.2	45 7		
Actual per cent decrease	.....	100 0	84 5	59.0	42.1	31.7	24 5	15.7	11.5		
Adjusted per cent. decrease	.....	100.0	77.5	59.0	42.1	31.7	22.1	15.7	11.5		
Lease E	1	40,006	71,324	71,615	62,941	54,730	50,366	39,217	33,628		
	2	459,942	561,452	330,333	144,093	60,738	31,507	33,268	16,705	19,511	
	3	120,226	80,161	44,692	46,060	42,151	36,190	26,762	19,885		
	4	95,261	65,510	52,451	42,958	36,379	29,332	20,613	19,068		
	5	35,379	48,348	37,386	27,621	22,717	18,848	14,750	15,310		
	6	55,313	81,665	70,313	56,408	52,084	42,911	38,718	32,942		
	7	108,065	111,923	93,979	77,027	48,846	40,024	29,250	21,096		
	8	97,224	76,707	66,818	59,453	56,310	45,883	52,290	50,000		
Total 8 wells	.....	1,011,416	1,097,090	767,587	516,561	373,955	295,061	254,868	208,634		
Average product per well per day	.....	346.3	375.7	262 8	176.9	128.1	101.0	87.3	71 4		
Per cent. I. P.	.....	100.0	108.5	75 9	51.1	37.0	29.2	25.2	20.6		
Lease F	3	210,214	54,474	24,700	19,943	22,454	34,896	36,362			
	6	160,433	16,426	9,340	8,777	7,338	7,938	6,434			
	9	43,823	47,804	25,939	16,945	14,912	14,950	11,218			
	10	31,337	34,829	12,750	12,175	10,527	8,468	8,068			
	17	3,614	11,143	8,191	4,468	2,963	3,048	2,800			
	26	58,716	32,742	27,379	19,438	15,367	12,600	10,800			
	27	81,913	49,236	31,070	21,437	19,757	18,000	17,000			
	31	26,165	23,402	19,659	15,806	12,599	9,400	7,450			
	32	42,514	38,730	29,340	24,072	20,529	17,800	15,900			
Company G	5	232,923	484,654	381,332	342,526	311,551	249,286	35,429			
	8	54,869	55,480	44,970	19,628	12,819	8,041	8,119			
	10	993,971	314,172	244,795	154,392	136,237	74,578	69,774			
	11	186,638	127,033	65,038	46,372						
	12	40,167	40,614	19,586	15,211	12,035					
	14	36,486	33,205	18,576	15,076						
Total 3 wells	.....	1,281,763	854,306	671,097	516,546	460,607	331,905	113,292			
Average product well days	.....	1,170 6	780.2	612.8	471.7	420.6	303 1	103.5			
Per cent. I. P.	.....	100.0	66.6	52.3	40.3	35.9	25.9	8.8			

* 23 wells. ** 21 wells.

Santa Maria and Lompoc Oil Fields

COMPILATION OF AVERAGE DECLINE OF NET PRODUCTION OF ONE WELL

Property	Well No.	1st Year	2d Year	3d Year	4th Year	5th Year	6th Year	7th Year	8th Year	9th Year	10th Year
Lease H	1	181,219	152,510	89,642	64,543	33,984	23,562	16,715	17,613		
	2	92,541	68,830	39,124	34,509	18,594	16,283	12,900	8,800		
	4	20,006	28,234	10,752	12,274	7,520	5,829	5,407	4,050	3,842	
Total 3 wells	.....	293,766	249,574	139,518	111,326	60,098	45,674	35,022	30,463		
Average product per well per day	.....	268.2	227.9	127 4	101 7	54 9	41.7	31.9	27.8		
Per cent. I. P.	.....	100.0	85.0	47.5	37.9	20.5	15 5	11.9	10.4		
Lease I	2	143,278	106,605	75,952	64,418	19,606	17,656	17,682	14,520		
	3	144,995	45,579	26,834	33,864	23,172	12,425	9,400	5,800		
	4	45,596	70,789	58,406	29,746	24,426	19,233	13,701	12,453	13,605	
	5	57,146	50,721	43,223	24,000	23,180	22,566	25,091	23,400		
	6	160,962	224,487	94,470	42,898	30,807	36,183	23,642	15,308	9,339	
	7	102,157	73,618	45,453	29,765	19,401	18,669	13,705	6,492		
	8	20,158	27,850	16,965	15,641	9,854	10,014	7,554	6,334		
Total 7 wells	.....	674,292	599,649	361,303	240,332	150,446	136,776	110,775	84,307		
Average product per well per day	.....	263.9	234.7	141.4	94.0	58.9	53.5	43 4	33 0		
Per cent. I. P.	.....	100.0	88.9	53.6	35.6	22.3	20.3	16.4	12.5		
Lease J	3	101,456	61,291	60,090	49,748	35,387	25,886	18,490	16,796		
	4	62,739	38,711	23,193	14,132	11,617	8,225	7,225	6,270		
	5	46,388	33,762	25,940	13,096	9,148	7,050	5,393	4,170		
Total 3 wells	.....	210,583	133,764	109,223	76,976	56,152	41,161	31,108	27,236		
Average product per well per day	.....	192.3	122 1	99.8	70.3	51.3	37.6	38.4	24.8		
Per cent. I. P.	.....	100.0	63.5	51.9	36 5	26.6	19.5	20.0	12.9		
Lease K	[a]1	1,187,473	343,817	96,471	77,120	71,227	82,772	84,901	88,140	88,144	86,173
	4	195,234	127,221	69,860	51,211	31,037	8,676	14,575	10,170		
Total 2 wells	.....	1,382,707	471,038	166,331	128,331	102,264	91,448	99,476	98,310		
Average product per well per day	.....	1894.1	645.2	227.8	175.8	140.1	125.2	136.2	134.7		
Per cent. I. P.	.....	100.0	34.1	12.0	9.3	7.4	6.6	7.2	7.1		

[a] 16,000 bbl. have been subtracted for well No. 2 for first 2 years—No. 2 being run with No. 1.

Wages Paid in Each Field

Field	Drillers		Toolies	Firemen	Pumpers	Gang Pusher	Well Gang
	Rotary	Standard					
Coalinga	$230.00	$7.00	$4.50	$4.00	$3.50	$4.50	$3.50
Kern	....	6.50 to 7.00	4.00 to 4.50	3.25 to 3.50	3.00 to 3.50	4 00 to 4 50	3.15 to 3.50
Midway, Maricopa & McKittrick	230.00	7 00	4.50	4.00	3 50	4.50	3.50
Coast	....	5.50	3.50	90.00 to 140.00	80 00 mo.	100 00 mo	80.00 mo.
South	6.50	5.50	3.00	100.00 mo.	2 50	100 00 mo.	2.50
Lost Hills & Belridge	230.00	7.00	4.50	4 50	3.50	4 50	3.50

Field	Laborers and Teamsters	Gas Engine Man	Carpenters	Mechanics	Gagers	Rig Builders	Electricians	Black-smiths
Coalinga	$3.00	$150.00	$5.00	$5.00 to 6.00	....	....	$125 00	
Kern	3 00 to 3 25	....	4.00					
Midway, Maricopa & McKittrick	3.00 to 3.50	4.00 to 6.00	4.00 to 5.00	5.00 to 6.00	75.00 to 90 00	6.00	125.00 to 180 00	$5 00
Coast	80.00 mo.	105.00 mo.	....	5.00	....	5.00	....	4.00
South	2.50	100.00 mo.	90.00 mo.	....	....	5 00	85.00	4 00
Lost Hills & Belridge	3.00	5.00	5.00	5.00 to 6 00	75.00	6.00	....	5.00

One curve, which was used in computing the theoretical production from new wells on the Newlove and Hartnell properties, was compiled from the data on all the Union Oil Co. properties in the field. The other curve was constructed for use on the remaining properties and included the data on all the properties except the Hartnell and the Newlove. This method was pursued for the reason that the conditions regarding production on the Hartnell and the Newlove properties were dissimilar to those on the remaining properties in the field. In the Lompoc field the present wells have been widely spaced, therefore the decrease in production per well per day has been more gradual than would occur in an area of closer drilling. As these data, therefore, would not apply to a drilled up condition, the Santa Maria curve, which excluded the Newlove and Hartnell production, was used, as the general conditions are similar to those of the Santa Maria field.

In Orange County no individual well data were available over any appreciable period. As the conditions of thick, saturated sands approximate those of Coalinga, the same decline was used for all properties with the exception of the Union Oil Co.'s Graham & Loftus lease, where a curve developed from the production of all wells drilled to date on that tract was used.

In Ventura County no individual well data were obtainable, but as the wells were drilled, in most cases, 20 years ago and the properties produced continuously over this period, the decline in production from the entire area eventually approximated that of one well and the ideal curve was deduced from this data.

Comparing the different curves on a percentage basis, the maximum deviation of any one curve from the average is less than 10 per cent. This is one of the most notable facts brought out by this work.

As an example of the use of these curves in the calculation of the production from the undrilled areas, suppose the new wells on a certain tract to have an assumed initial production over the first year of 100 bbl. per well per day, then the average production per well per day for the second year will be 79.7 bbl., as is shown in Fig. 1. The sum of all these figures, representing the average production per well per day, multiplied by 365 will give the total production from one well, and multiplied by the total number of wells will give the ultimate production from the undrilled area. For figures above or below 100 bbl., the total production will be in direct proportion.

Fig. 2 is a graphic representation of these calculations. The assumed initial production for new wells is shown at the base of the chart and the diagonal straight line above shows the total production from one well. The curve line shows the year in which the average production per well per day will reach a production of 1 bbl. for varying initial productions.

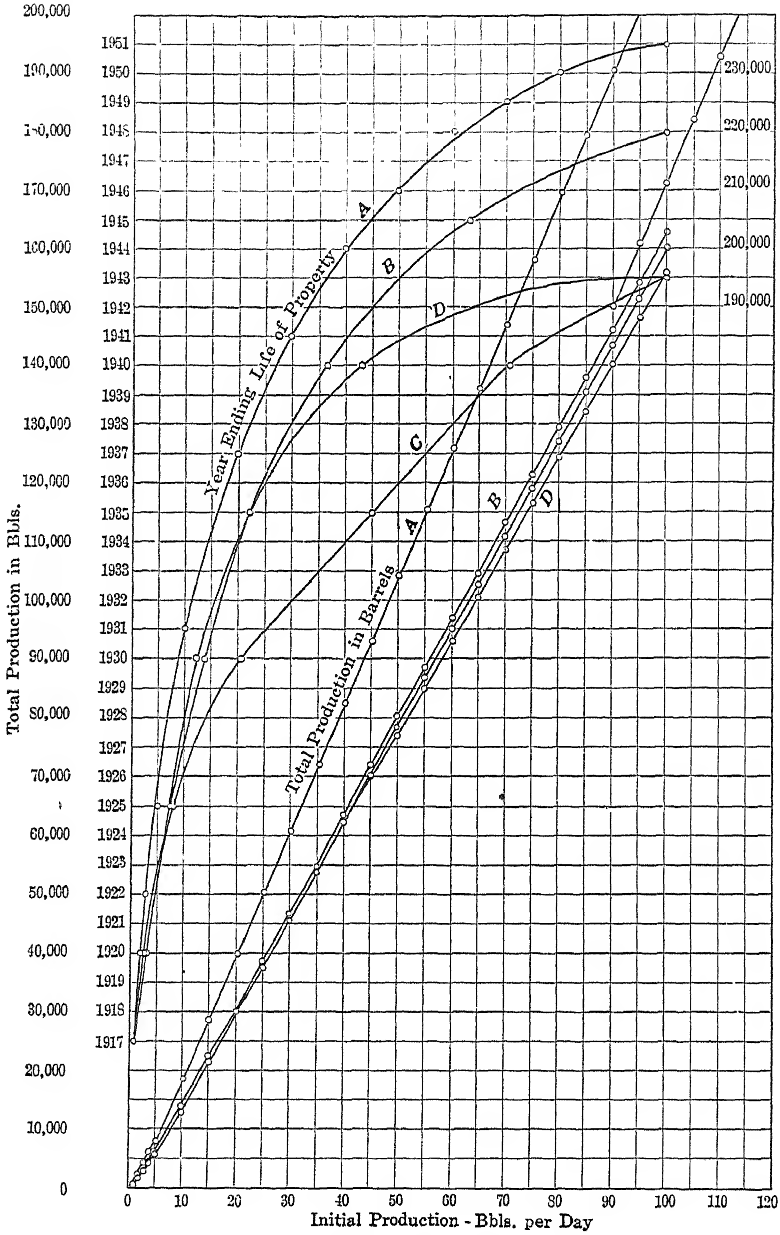

FIG. 2.—THIS SHOWS BY DIRECT READING THE ESTIMATED PRODUCTION OF ONE WELL AND THE YEAR OF ENDING AT THE 1 BBL. PER DAY.

Illustration: New well with initial production of 50 bbl. per day first year, read up to intersection of total production line, thence to the left and read 104,000 bbl. Going back to the 50-bbl. line and up to the intersection of the curve line, thence to the left, 1946 will be the year ending the production at the 1-bbl.-per-day point.

A = Coalinga curve. C = Santa Maria curve.
B = Maricopa curve. D = Newlove and Hartnell curve.

In computing the total production from each property, the following steps were taken:

1. To divide each property into two areas, drilled and undrilled.
2. To compute the total ultimate production from the drilled portion by constructing a curve which showed the average past production per well per day and projecting this curve for the future.
3. To compute the total recoverable content from the undrilled area, assuming that all new development is completed in 1916 and maximum production occurs in 1917.
4. To combine the yearly estimates of 2 and 3 in each case as the total estimated production per year for the entire life of the property.

Well Spacing

In order to divide the area into drilled and undrilled portions, it was found necessary to construct a table showing definite well spacing for

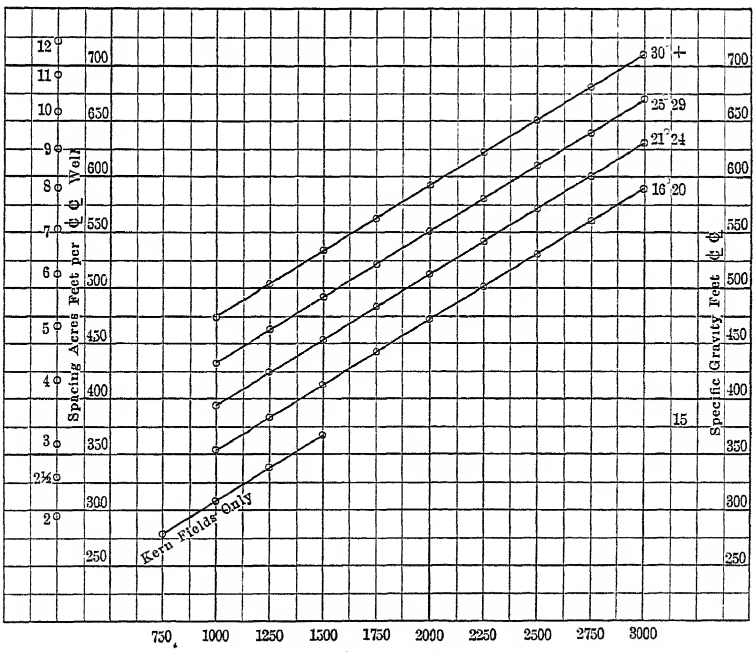

FIG. 3.—WELL SPACING.

the varying conditions of depth, thickness of sands and gravity of the oil. The thickness of the oil sands underlying each property is undoubtedly a factor to be reckoned in the ultimate production per acre, but as in the majority of areas considered in the valley fields the sands are thickest in the shallow wells and thinnest in the deepest ones, this

fact could be taken care of by judicious use of the chart. Since the gravity of the oil, as a general rule, varies from heavy, viscous grades in the shallow wells to light, mobile oils in the deeper ones, this also is taken into account. Fig. 3 was constructed by collecting and tabulating data

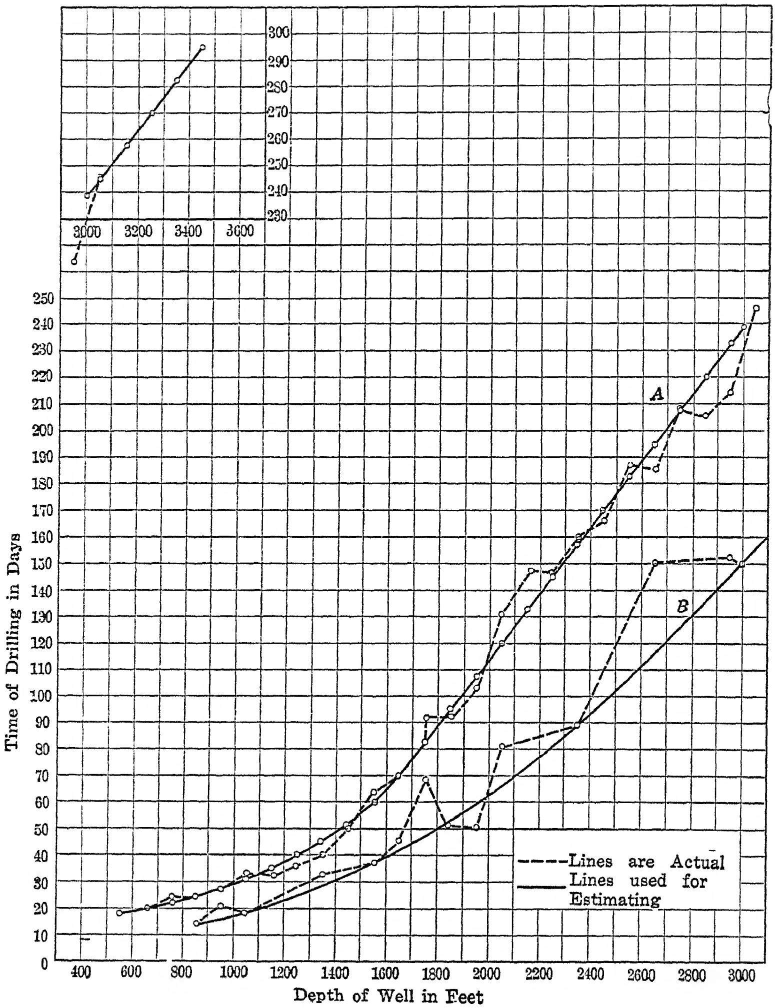

FIG. 4.—AVERAGE DRILLING TIME FOR DEPTHS AS LISTED.

A = Standard drilling, Coalinga, Midway and Kern fields B = Rotary drilling, Coalinga and Midway fields.

on all the fully drilled up conditions of the properties in the San Joaquin Valley oil fields.

The well-spacing chart is constructed so that the spacing of wells from 750 to 3000 ft. (228 to 914 m.) in depth can be established. The varying depths are shown at the base of the chart and the spacing either

in acres per well or the distance between wells is shown in the left-hand margin. The four diagonal lines are used for the varying gravities from 16° to 20° Bé. for the lower line, 21° to 24°, inclusive, 25° to 29°, inclusive, and 30° and higher for the three succeeding lines. The chart was used as follows:

From the logs of the wells in the immediate vicinity, the average depth of the new wells to be drilled in the undrilled area was determined and the point selected on the diagonal line corresponding to the gravity of the oil to be obtained. Tracing this point horizontally to the left-hand margin, a figure is found which gives the spacing for this depth.

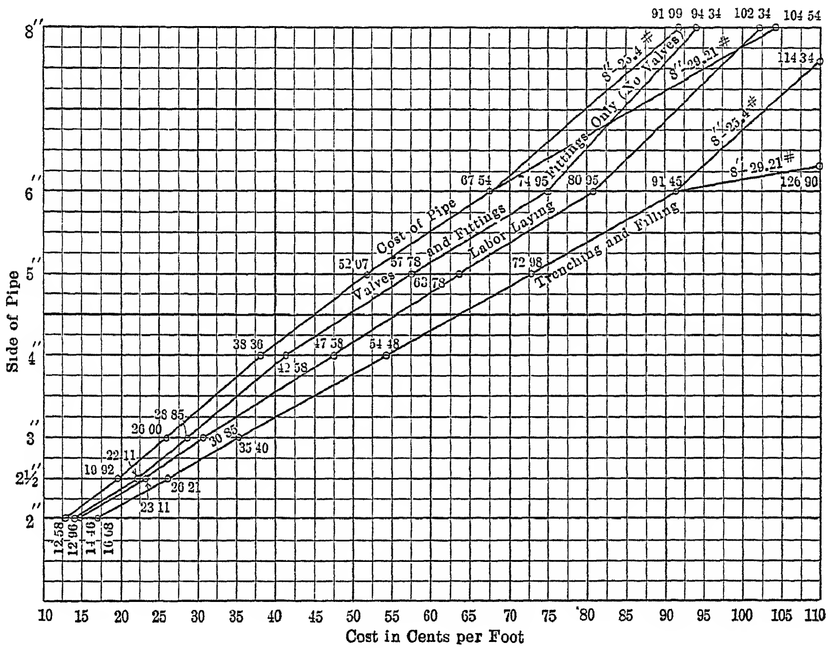

FIG. 5.—COST OF OIL-FIELD PIPES LAID.
(These prices do not include cartage. Valves not included above 6 in.)

Drilling Time

Fig. 4, curve *A*, shows the time of drilling wells with a standard rig for varying depths. The data compiled includes the results from over 700 wells of various depths in the Coalinga, Kern and Midway fields. The amount of casing used was established in uniformity with the practice on the properties considered. Fuel oil, tools, drilling lines, derricks, rig irons, belts, engines, and haulage are all figured to standards. This method insures uniformity and is free from the variations which show on accounting records of the various companies. The red line on the chart

shows the actual results of the compilation of these data, and the blue is the assumed average.

Curve B is constructed similarly for drilling time with a rotary rig.

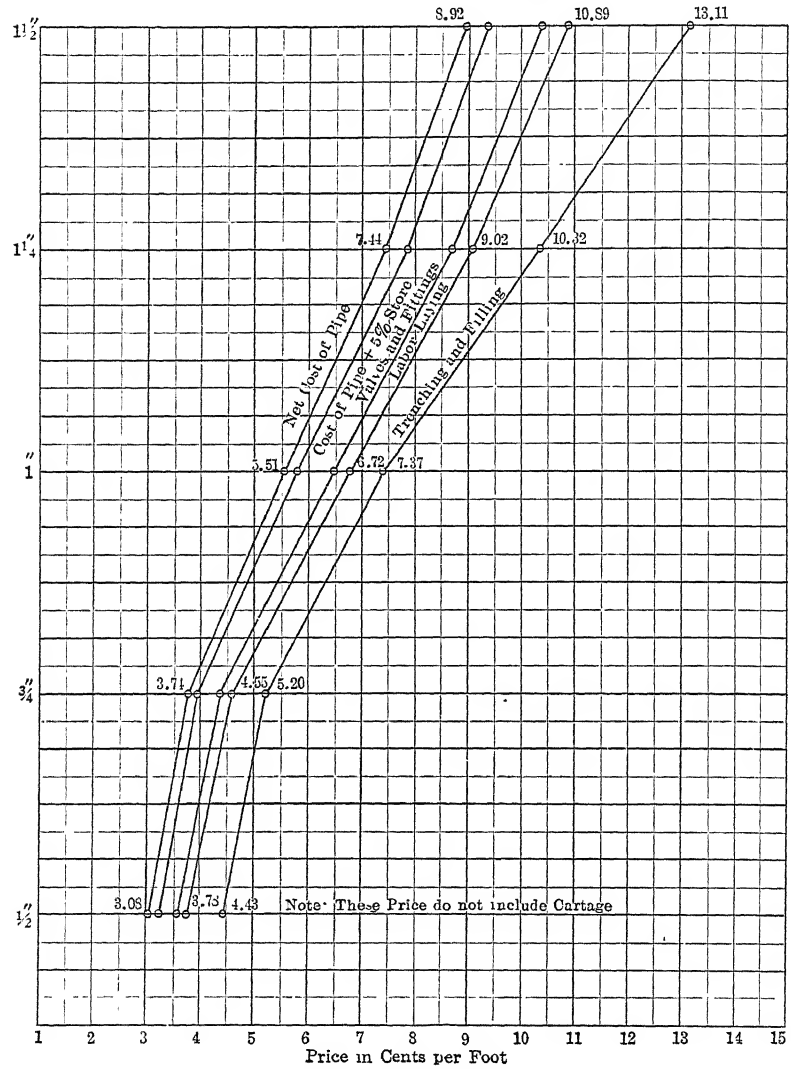

FIG. 6.—COST OF OIL-FIELD PIPE LAID.

Pipe Lines

Fig. 5, 6 and 7 show the cost of various sizes of pipe from 1½ up to 6 in. in diameter and were constructed from actual data covering approximately 200,000 lin. ft. of pipe laid. These may be used in valuing lines already laid and in determining the cost of new lines for future development. They are compensated to include all necessary fittings.

Ultimate Production

To compute the total ultimate production from the drilled area, a curve was constructed showing the average production per well per day for the property during the past years and this curve was projected for the future by applying the percentage decrement in past production to the future. In the case where actual data were available showing that certain idle wells could be made to produce by redrilling or other repairs, or where the past production curve showed an abnormal decline, due undoubtedly to market conditions, it was adjusted to offset this decrease.

It was imperative that all properties be valued on a relative basis and as the present value of each would vary according to the time interval

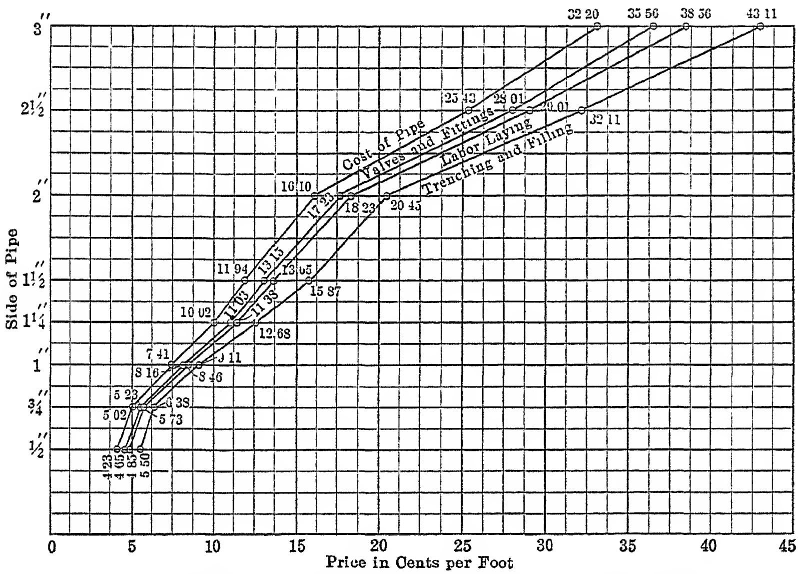

FIG. 7.—COST OF OIL-FIELD PIPES LAID (GALVANIZED IRON).

chosen for the drilling of new wells, it was recognized that some standard period must be adopted during which each property should be completely developed. It is obvious, other conditions being equal, that if property "A" is completely drilled at once and its maximum production obtained immediately, it will have a much greater value than property "B" on which new development is deferred, and which is presumed to continue its present production at the normal rate of decline. The difference is due to the fact that the present value of one year's net receipts is smaller, the longer its actual payment is deferred. In order to avoid these discrepancies and to treat all properties equitably, each has been theoretically drilled up in the year 1916. The maximum production, therefore, occurs in 1917, and during the succeeding years declines according to the

established decrease curves until such a time as it is no longer profitable to produce oil from the property.

In computing the total recoverable content from the undrilled portion, the first step consisted in determining from the structural conditions the average depth of the wells to be drilled, and by the use of the well-spacing chart the number of new wells to be drilled. By dividing the ultimate production from the drilled area by the number of acres drilled, a figure is obtained which shows the total production per acre from this portion. The calculation of the future production from the undrilled area is based upon the past performance of wells in the immediate vicinity. Due consideration is given to lessened individual well production with complete development of the tract and to the total ultimate production per acre from contiguous drilled tracts.

Fig. 8 was made for estimating and is based on the Coalinga curve volumetric production of a well to the 2-bbl. point of decline, and is the amount that such quantity of oil will yield at the varying profits over the operating charges per barrel with all interest charges at 8 per cent.

The average cost of drilling wells and equipment is that of all fields and is closely approximate for estimating purposes. For illustration, the average cost of future equipment per well where new wells have to be drilled, for a 2000-ft. (609-m.) well is $2400. This is meant to include extra pipe lines, proportion of electric equipment, etc. The drilling of such a well would be closely $18,200. Average upper line for both, $20,600. It is necessary to reduce the upper curve amount by 0.926 to conform to the deferred 8 per cent. basis of the calculation, which would be $19,076.

If the operating costs are estimated to be 28 c., the profits will be 22 c. for 50-c. oil. At this value a line run horizontally to the 22-c. line, then vertically to base, will show 68 bbl. This is the least initial production that such new wells must have in order to repay the cost and interest over the operating expense.

Complete production and cost data were obtained wherever possible on properties that approximated fully drilled-up conditions and were not forced to curtail production on account of market conditions. This information was used as a guide to what might be expected from the surrounding properties in the immediate area.

By reason of the inefficient system of accounting found to prevail with most companies, it was impossible to obtain any data of value relating to the costs of operating and developing on each individual property. If such data were available it would have greatly facilitated the compilation of future working costs.

In computing the values, the following steps were taken:

1. To estimate the future working costs per year from all data available.

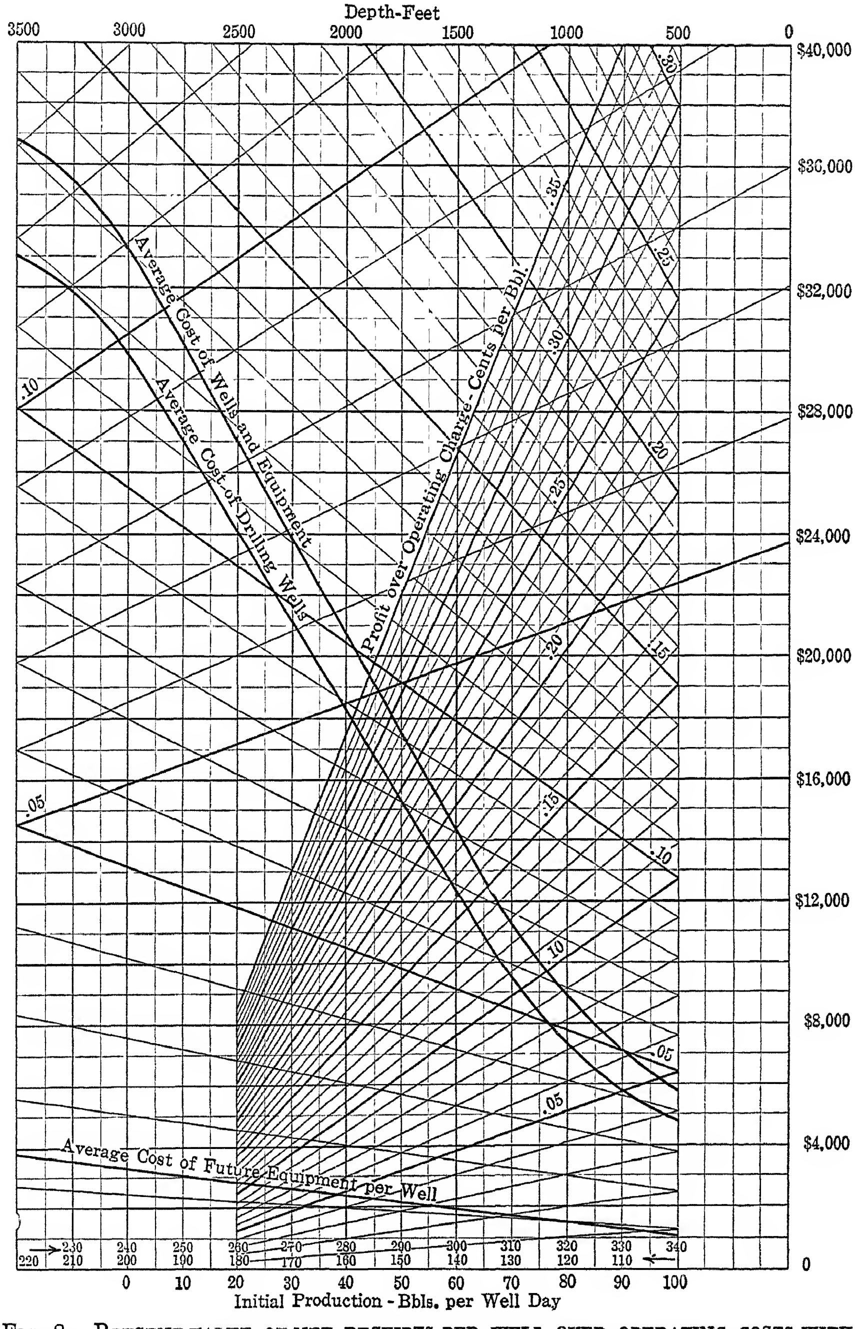

FIG. 8.—PRESENT VALUE OF NET RECEIPTS PER WELL OVER OPERATING COSTS WITH OIL AT 50 C. PER BARREL (MINIMUM PRODUCTION PER WELL DAY, 2 BBL.).

2. To compute the net receipts per year, *i.e.*, the difference between the gross receipts and the total yearly expenditures.

3. To compute the present value of each year's net receipts, allowing a specified interest of 8 per cent. per annum, and returning each year a proportionate part of the capital with the 8 per cent. interest, thus obtaining the present value of the future production.

4. To add to this the salvage value of the excess equipment, thus obtaining the total present value of the entire property.

In making estimates for new expenditures and operating charges, standards were adopted and applied to all properties where conditions were similar. These standards were the result of careful investigation of present working costs of all kinds.

In the case of new wells, drilling costs have been computed from all the past data available and are consistent according to fields and depths. The new equipment was also estimated according to the requirements of the property, the value being carefully computed from present-day prices as quoted by supply houses. These estimated expenditures were all charged and applied as of the year 1916, so that all new wells and equipment would be placed in that year for a maximum production in 1917.

In computing the annual cost of operation for the future, each item of labor and material was considered and charged according to the most economical method of operating, with due consideration for the present method in use on the property at the time of taking the inventory. On properties having wells less than 1500 ft. (457 m.) deep, motor-driven jacks were considered the most economical form of power, and for properties having wells over 1500 ft. deep, those using gas engines at the present time were assumed to continue this method of operation throughout the life of the property, while those operated by steam engines in the past were changed to direct electric motor-driven installations, the assumption being that this latter method is the more economical.

The computation of the net receipts, and from this the present value, is purely mathematical The table used for the computation of present value was taken from Hoskhold's *Engineers' Valuing Assistant.*

The surface equipment that can be given a present salvage value is all the equipment that can be removed from the property at the present time without interfering with its future operations. This includes drill tools, warehouse supplies, live stock, casing on the rack, mechanical equipment, etc. All other equipment, such as derricks, pumping plants, pipe lines, etc., is considered in the allotment of expenditures for the future operation of the old wells, thus the operation of these wells will be carried on without the addition of any new investment. The net cost of operation per barrel, therefore, will be determined solely from oper-

ating costs and, consequently, will be lower than if an investment charge were necessary.

The method adopted by the Committee in the computation of values of the Agency properties is considered to be far superior to any of the other methods proposed, for the following reasons:

First.—The history of development of the property as well as that of the adjoining properties is considered.

Second.—The operating cost is computed from actual figures obtained in the field, all necessary additions to plant being given full consideration.

Third.—In computing the present value of the actual net receipts for each year, amounts that can be redeemed with interest at 8 per cent. per annum are shown.

Fourth.—This method more nearly approximates the actual conditions that will exist in the future than any other method yet presented; is regular in its application to all properties and will give results that, when applied to a property, will admit of a fair and conservative return on the investment.

DISCUSSION

F. G. Clapp, New York, N. Y. (written discussion*).—I have read with the deepest interest the very excellent paper by Mr. Requa, giving what is to-day most needed, a very clear statement as to the cost of the production of crude oil in the various fields. I consider it a very valuable paper because of the necessity of dealing with the cost of production of this, in many respects, incomparable fuel. Whatever processes of appraisal have been found most correct and feasible in one field or group of fields will generally prove most adaptable in others. So far as the Carolina fields are concerned, Mr. Requa's paper appears to outline the most up-to-date processes of appraisal. It remains, then, to discuss and adapt these and to make such revisions in methods and processes of calculation as will give us results elsewhere.

The trouble about most attempts to place a value on oil lands, whether in this country or elsewhere, has been that many of the so-called "experts" called upon to express an opinion either have not possessed the requisite engineering and geological knowledge to make an accurate appraisal of the lands, or that they were not furnished with sufficient information for the purpose in hand. The Independent Oil Producers' Agency of California, for whom Mr. Requa's original report was prepared, had many advantages in this respect not generally available to engineers making reports, as all existing information seems to have been at the

* Received Feb. 27, 1918.

experts' disposal within the limits of a large number of properties, practically commensurate with the extent of the fields in question. Hence the report could be and was more accurate than any similar report for a single company is likely to be in other fields. Very few companies are so exempt from competition that all the data on neighboring leases of other companies will be freely turned over to them. In many companies, certain available data are concealed from the engineer who makes the reports, particularly if the properties are supposed to be worth less than their apparent value. In the case of other companies, having the best of intentions, the data are insufficient to help the engineer greatly in his appraisal, simply because the oil business has been so unsystematic in most fields that only the largest and wisest companies have kept accurate figures regarding runs and gravity of oil from individual wells and from different depths. In many wells, which ran wild for days or weeks in the older fields, there was a waste which is not recordable with exactness. These and many other difficulties confront even the most experienced expert in actual practice outside of the California fields. We may justly say, therefore, that an engineer in other fields of the United States and in the European, South American and Asiatic fields, must not only begin where the Independent Oil Producers' Agency commenced, but must go to greater extremes of time and distance to get information of value.

It is possible, in the case of some fields where the character of the sands, water conditions, gravity, etc., are similar to the California fields, that certain of the California curves may apply, in the absence of better information, for approximate calculations of total production. The similarity of the curves as shown in Mr. Requa's paper might lead to this conclusion. The similarity of his curves, however, is due mainly to the similarity of producing formations throughout the California fields. The rate of decline and consequent shape of the curves in some other fields may be similar, owing to approximately similar conditions in the sands (sand being used here as a generic term to express the producing formation, whether it be sand, sandstone, limestone or shale). Since very few fields are identical with California fields in geological age, structure, texture, and water conditions, it follows that even the average California curve will suffice only in the most general way in another field; and will not apply elsewhere for accurate calculations like those made in the paper in question. For instance, in the Oklahoma, Pennsylvania, West Virginia, Kansas and Illinois fields (all of Carboniferous and earlier age) the sands are much harder and more compact; and while the wells have generally smaller initial productions, they hold up much longer than do the California, Texas, Louisiana and Mexican wells.

Since the eastern and mid-continent fields produce entirely from the Carboniferous formations, they are all firmly compacted, and the

constituent grains of the formations are not, as a rule, displaced in any degree by the movement of the oil into the well. Consequently, the decline in production is comparatively slow. Moreover, the grade of the oil and price secured make it possible to pump the well down to a much smaller output per day than is the case in California. While Mr. Requa assumes the abandonment of the well at the time when the production is 1 bbl. per day, this would not do at all in the East, as the majority of wells are pumped far lower than that. Many wells have been drilled where only 1 bbl. per day was expected from them, and most wells in the Pennsylvania fields are pumped as low as 1/8 bbl. per day. The several different sands which produce oil in the same well, and consequently the several stages in drilling of a field, introduce other corresponding difficulties.

Summarizing the foregoing general discussion, we must say that the methods applied in California are applicable in fields throughout the world under ideal conditions; but that these ideal conditions will rarely be encountered, and that in no circumstances should it be assumed that the curves for any particular field will apply in fields having different geological conditions.

The subject of valuation brings up many mistakes which have not been generally acknowledged or considered by the oil fraternity. One of these is the habit some companies and individuals have of using the terms "dome" or "anticline" as synonymous with an "oil field." Nothing could be further from the truth, as every experienced oil geologist knows; yet I have seen reports on so-called "domes" bought and sold on the supposition that drilling a well upon them would result in unquestionable success. In the first place, many factors are necessary besides the domal or anticlinal structure; and, secondly, some of the structures thus sold have not been domes or anticlines at all, but either absolute frauds, or the illusions of pseudo-geologists not qualified to make such determinations.

Another false assumption by some of the oil fraternity, especially in California, is to gage the probable production of a well by the thickness of the sand supposed to underlie the surface at a particular point. So far as I know, California is the only part of the United States where this practice has been extensively used; and it may be safe in that State to take it as some indication where other data are not available. In other fields the method will not apply at all, owing to change in structure, thickening and thinning of the sands, local hardening and other factors.

The emphasis placed by Mr. Requa on the spacing of wells in different fields and in different parts of the same field is very important; and in any field where different spacings apply in different parts, special curves should be used for the closely spaced and widely spaced portions of the field. This discrepancy will be greatest in fields where a part of the field

consists of a town-lot development, like the Breman field of Ohio, or like the Spindletop field of Texas. The latter, though not strictly a town-lot development, was parcelled out by speculators in such a way as to be one of the worst examples of close drilling. The wells in these cases, though some of them originated in enormous productions, dropped off so rapidly that they were abandoned long before outlying wells had dropped to comparable production.

Appraisers must beware of accepting as infallible the principle that the total production and year of ending a given well can be calculated from its initial production; as some wells of large initial production drop off more rapidly than smaller ones in the same field. In the Pennsylvania fields, many wells of large productions are long since abandoned, while neighboring moderate producers are still being pumped. In the California fields, uniform conditions of sands probably render this factor more constant than elsewhere.

The correct spacing of wells has, of course, nothing to do with their depth, except as the latter is an element entering into the cost. The correct spacing, largely a matter of experiment and experience, is based on the texture, size and shape of grain,amount of gas, water conditions, etc., of the sand to which the wells are to be drilled. Wells should not be and generally will not be spaced closer than necessary to obtain the maximum amount of oil obtainable at a profit, and in this spacing the depth is only one factor of several.

The method described by Mr. Requa appears to be the best yet suggested. This will doubtless now be more commonly applied to other fields, which will take time and care, and all the precautions used and suggested must be taken into account, with the frequent addition of others which have not been mentioned, but which will occur to the engineer making the appraisal. In all valuations of oil properties, it should be borne in mind that the undrilled portion of the property will seldom follow the same basis of figuring as that which has been drilled, and the differences between the drilled and undrilled portions must be most carefully decided on the basis of structural and stratigraphic geology and of drilling and operating costs before making the final calculations.

W. N. Best, New York, N. Y. (written discussion*).—My knowledge of crude oil does not relate to its production but to its burning in various forms of equipment. We see from Mr. Requa's figures that the greatest production of an oil well occurs during the early years of its history, and seemingly each succeeding year shows a marked decline in its production. Mr. Requa's paper intimates that in order to increase the supply it is necessary to find new oil fields. My thoughts are centered upon the economical use of this fuel, and its value as compared with coal, wood, or

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* Received Feb. 15, 1918.

natural gas in various installations. The data I am about to give are the result of hundreds of tests, and show conclusively that a great many manufacturers are using oil in places where they should not use it.

In locomotive service, it requires 180 gal. of oil to replace one long ton of bituminous coal, having a calorific value of 14,000 B.t.u. In stationary boilers it requires 147 gal.; in forging furnaces, 80 gal.; in heat-treating furnaces (low temperatures) 72 gal.; while in flue-welding furnaces it requires only 58 gal. of oil. The economy in the latter case is due to the fact that, when using bituminous coal, you cannot weld a flue without first coking the fire, and in so doing, you waste practically all of the gases of the coal. In the natural-gas districts around Pittsburgh, in furnace practice 6 gal. of the average crude-oil fuel are equal to 1000 cu. ft. of natural gas, while 3.25 gal. of oil are equal to 1000 cu. ft. of illuminating gas (500 to 650 B.t.u. per cubic foot); 3.25 bbl. of crude oil (42 gal. per barrel) are equivalent to 5000 lb. of hickory or 4550 lb. of white oak in boiler practice.

For accuracy of temperature, there is no other fuel that can be so perfectly controlled, and its heat so evenly distributed, as oil. It is advisable to use as few burners as possible; one burner is always preferable to two or more in a furnace, no matter how large or small that furnace may be.

Many forge manufacturers have assumed that, because they can burn oil economically in their forge furnaces and obtain greatly increased output while also extending the life of the dies, they can also use oil advantageously in their power plant; but they are astonished to find the difference in the quantities of oil required to replace a ton of coal in the two services.

I believe that, in the future, no power plant will be considered complete without equipment for both fuels, coal and oil; and while it would be folly to use oil continuously as a boiler fuel in those sections of the country where good coal is cheap and oil is high, it is possible, at all times, to have oil as an emergency fuel, even though the oil apparatus may be installed 5 years before an occasion arises to use it. As a result of the past winter's experience, thousands of plants on the Atlantic Coast now see the need of an emergency fuel, and I believe that it will be considered good practice to install oil as an emergency fuel before another winter.

We know the value of oil fuel for meeting peak loads at plants where the power demand is intermittent; oil is often burned in combination with coal for 2 hr. in the morning and 2 hr. in the afternoon. It has been found more economical to use oil here than to carry a few extra boilers with banked coal fires. to meet the peak loads. The advantage of oil in this connection is that the boiler rating can be increased 200 per cent. much more quickly than with any other fuel, and also without conflicting with the ordinary coal firing, whether by hand or by stoker.

Oil burners can be installed in combination with coal or coke in order

to obtain better metallurgical results in large furnaces in which solid fuel is needed to melt metal; for by this combination a higher temperature can be attained and maintained. It is only in late years that we have learned the value of accuracy in temperature of molten metal.

I am also confident that oil will be developed as an emergency fuel in marine service, although it is too costly for continuous use. Vessels in the Atlantic trade could not economically use oil exclusively, but might use it as emergency fuel; but for vessels running into ports on the Pacific Coast, where good coal is high and oil is cheap, the latter is the more economical.

I prophecy that the nation which can give to its foundries, forge shops, tool makers, heat-treating departments, and other manufactures where accurate temperatures are required, all of the oil that they need, will be the foremost manufacturing nation of the world.

Eugene Wesley Shaw,* Washington, D. C. (written discussion†).—Mr. Requa's subject is one of great economic importance, yet relatively new, and he has been able to combine extensive practical experience with the talent of grasping the broad features of a problem that has many discordant details.

After examining Mr. Requa's paper with some care, I would like to ask a few questions about headings and entries in tables. For example, on page 529, why are there two tables together with the same heading in different forms? What does "Sheet No. 1" and "Sheet No. 2" refer to? I should like to know if account is taken of days when the well is out of commission, if "first year" begins with the first of the first year or of the first month, or the first day of the well's life—in other words, the actual significance of "number of days." Other questions arise concerning other tables.

I have been much impressed by several conclusions set forth or implied by the paper.

First of all, the total yield of an average well in several California fields is about five times its initial production times 365; that is, it yields roughly 1800 times as much in its lifetime as it does in the first day. Moreover, there is a remarkable similarity among the average wells for different fields, the minimum yielding about 1500 times the first day's yield and the maximum roughly 2000 times.

The rate of decline of the average well in the fields discussed is not uniform, as, of course, is generally realized, but itself declines and at a rate that shows a gradual decrease as the well becomes older. The curve for the average well has a relatively sharp flexure from the fifth to the ninth year, or while the well is declining from a third of its initial

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† Received Apr. 1, 1918.

yield to a sixth. Although the observed data do not extend beyond this period, and in some fields they do not extend to it, the range of possibilities is rather narrow and the extrapolation of the curve is done without danger of great error.

The similarity of the average curves is especially striking when compared with the data on which they are founded. The individual wells seem to show wide variation and much irregularity. In particular, although the average curves show very rapid decline in the first and second years, the figures in the tables (page 528) indicate that many wells make even more the second year than the first, and perhaps that most wells reach this maximum production on some day considerably after the well is brought in, so that the decline is not continuous from the beginning.

Perhaps it is a personal predilection, but I like to see an ideal curve as mathematically simple and regular as possible. I believe, however, that there is a sound reason for so constructing ideal curves, this being that errors are thus reduced to a minimum. To put it more concretely, suppose an ideal decline curve is to be constructed for the average well of a field containing many wells, only a part of which have recorded production figures. If the records of the known wells are averaged, and the average is plotted, there will be irregularities, though, due to the averaging, these irregularities will be of lesser degree than those of the curves for the individual wells. The best guess at the curve that could be constructed, if the records of all wells were known, is to be made by smoothing out the irregularities in the average for the known wells according to some law—in other words, attempting to find the average curve that would be determined if there were an infinite number of wells, and records of all had been kept.

Mr. Requa's ideal decline curve (see table on page 530) is not of this sort. In lopping off irregularities he comes to a series of values that are not definable in a simple mathematical formula, and although the values may approximate both the average of the observed yields, and the ideal average, or that of an infinite number of wells, they do not represent either of these curves. Steep-sided and narrow departures from regularity are eliminated, but broad irregularities are left in. The curve for an infinite number of wells would in all probability show a geometric decline, though it might involve a progressive increase in the decline of the decline in rate of production, or something even more complex. A curve with a relatively simple formula, that fits as closely as may be the observed values, is more likely to be the ideal curve of decline that all wells tend to approach than any other single line that can be drawn—certainly more so than one having an arithmetic decrease in the rate of decline, changing abruptly to a fixed decline. On the other hand, the arithmetic series may be as close an approximation as is needed for most purposes

and the integral feature makes it more useful than if fractions were involved.

A formula that seems to me applicable to the decline of individual wells is

$$y = a \times b^{x^c}$$

and it also seems probable, on theoretical grounds, that this formula will represent rather closely not only the decline of wells but of pools and groups of pools, the values of the constants, of course, being different for each case. For the decline in the production of oil in Illinois, the formula may be written

$$y = 28{,}601{,}000 \times 0.9^{x^{0.9}}$$

the values of the constants here given being only approximate and the large whole number being the production of the State in 1912, the beginning of pronounced decline. If $c = 0$, y is a constant and the curve is a straight line parallel to the X axis; if c is less than 1, the curve approaches both axes indefinitely; if c is greater than 1, the curve has a double flexure cutting the X axis at right angles and approaching the Y axis indefinitely; if $c = 1$, the curve straightens as it approaches the X axis, crossing it at an acute angle and approaches the Y axis indefinitely.

Fig. 2 of the paper presents a number of relations of much interest, though, as in Fig. 1, the significance of some features is not quite clear. Presumably the plotted points represent averages of observed values, for they show irregularity in spacing and alignment, and yet not nearly so much irregularity as individual wells would show. In any case, the total production curves are almost straight lines and indicate that the ultimate yield of a 20-bbl. well will be twice that of a 10-bbl. well, half that of a 40-bbl. well, and so on to the limits of the data, a 100-bbl. Santa Maria(?) well yielding in the long run 160,000 bbl., whereas a 5-bbl. well in this field yields about one-twentieth as much, or 8000 bbl. I believe that in the oil fields with which I am most familiar this relation would not hold, but still a positive statement cannot be made because the recorded data are so scant, particularly as regards the later history of wells, most of the wells with performance records being as yet only in their prime.

It is interesting to study the problem theoretically, though the results may be of little practical value. Apparently there are four main factors controlling the initial yield of a well: (1) thickness of pay; (2) size of pores and any other cavities in the reservoir, both individually and collectively; (3) pressure; (4) size of bottom of well. Perhaps quality of equipment and skill of drillers should be included in this list, but let them be classed temporarily as minor factors along with viscosity of oil, shape of pores, cementation of sand, etc. The rate of yield throughout the life of the

well depends on these and a number of other factors, such as any condition leading to clogging of the sand pores, or the tubing, the ability of water or some other fluid to follow up and take the place of the oil as it moves from the sand to the well ("dry sand" exponents to the contrary notwithstanding), the amount and distribution of gas (in solution, in small or large pools, in or above the oil), etc. The ultimate yield must depend principally on the volume of that portion of the reservoir from which the well can draw (controlled by character of sand, spacing of wells, ability of adjacent beds to yield water, etc.), and the percentage of recovery—a highly important but little known element, the variations in which may, in the lack of information to the contrary, be assumed to balance when any large number of wells is involved.

Now an inspection of this preliminary analysis, bearing in mind the general laws governing the flow of liquids and gases through capillary and larger tubes, leads one to the following presumptions concerning the ultimate yields of, for example, a 200-bbl. well and a 100-bbl. well. If the greater initial yield of the 200-bbl. well is due to greater thickness of pay, other factors being equal or in balance, its ultimate yield should be somewhat more than twice as much, because, on account of disproportionate increase in friction, a little more than twice the cross-section area of the oil stream would be necessary to double the output. With wells no larger than a few hundred barrels, this difference is probably negligible.

If the greater yield of the 200-bbl. well is due to greater diameter of pores, but not greater amount of pore space, the ultimate yield should be greater only in proportion as the percentage of recovery is greater. On the other hand, if the aggregate volume of pores is greater in the larger well, but their size not essentially different, the case would be similar to, if not the same as, that of greater thickness of pay.

If pressure is the sole cause of the difference in initial yield of the two wells, the ultimate yields should not differ greatly, and a similar inference must be drawn concerning the fourth important factor—size of bottom of well.

I would, therefore, expect, both from theoretical considerations and from the performance of wells with which I am more or less well acquainted, that, in general, a 200-bbl. well would hardly yield twice as much as a 100-bbl. well, and that a 10,000-bbl. well would be very unlikely to yield a thousand times as much in the end as a 10-bbl. well. On the other hand, in a single field of fairly uniform nature and perhaps a single main producing sand, it is quite conceivable that differences of initial yield are due much more to differences in thickness of pay and volume of pore space than to variations in average diameter of pores, pressure, or size of well bottoms, and hence that the ultimate yield of the wells might be roughly proportionate to their initial yield. Although this is admitted, I am rather strongly of the opinion that in the fields of

Pennsylvania, West Virginia, Ohio, Kentucky, Illinois, Texas, and Louisiana, that I have studied, the ultimate production of the large wells falls short of being proportional to their initial capacities Lewis and Beal find that in the Osage Reservation the well that has a big output for the first year has a much sharper decline than the small well (see p. 502.)

There are many other interesting and to me more or less surprising things in Mr. Requa's paper. I would have expected the curves in Fig. 4 to show that after a depth of 2500 or 3000 ft. had been reached, the time required to drill 100 ft. would increase, and I would expect the "average cost" curves in Fig. 8 to show an increase in cost per foot with depth, instead of uniformity from 1200 or 1500 ft. to about 3000 ft., beyond which there is an abrupt decrease in cost per foot. I am also rather surprised that all the profit curves in Fig. 8 drop to zero at 20-bbl. initial production, implying that a 21-bbl. well might return 35 c. a barrel on its output—as much as a 300-bbl. well could—but a 19-bbl. well would be unprofitable.

It is worthy of note that Mr. Requa's "methods of valuing oil lands" are strictly technologic, the main factors taken into account being production records and cost statistics, and they do not take into consideration geologic facts such as thickness of pay, size, shape, and aggregate volume of pores, gas in the sand, water that may get into the sand from one side of the pool or above or below, character of other strata in the region, etc. I believe that there are a good many geologic features which can be taken into consideration to advantage in the valuation of oil lands. The importance of each varies from place to place and perhaps several may be ignored without error, in appraising a property in the middle of a well drilled field. I believe also, as I pointed out in *Bulletin* 629 of the United States Geological Survey, that the doctrine of chances has much value in some places. Indeed, it has long played, incognito, a part in the opinions of experienced men as to the values of oil lands, and it may as well be recognized by its proper name and occasionally used mathematically.

Measurements of pressure are of greater value in appraising gas lands, but can be used to advantage, I believe, also for oil, especially where there is considerable gas with the oil. The comparison of closed pressure decline and volume produced, perhaps first outlined in the report referred to above, may be of considerable value. If a well yielding gassy oil has a closed pressure of 1000 lb. at one date and, after yielding a measured but not large quantity of gas and oil, drops to 100 lb., the quantity remaining in the ground is presumably much smaller than if, with the same output, the pressure had dropped only to 500 lb. Of course, in the absence of gas this side light could not be used.

M. L. Requa (author's reply to discussion*).—As to the questions raised by Mr. Shaw, the tables on pages 528 and 529 were made from the years' records of the various wells, and the figures represent actual production, including all delays and stoppages during the year periods. "First year" means the first year of a well's production, as the heading indicates—from the day it was put into commission as a pumping well—and will explain why some of the first year's are lower than the second year's records, as sanding up and many other happenings in this (then) new territory delayed production. The figure for each year represents the production during one year of the well's life, not during a calendar year. The data for Company "C" were not obtained until after the first compilation was completed, and as the quantities were so nearly equal, we averaged the totals, which gives the same results, preferring to keep new data separate.

It must not be overlooked that this work was done under stress of time, and where practicability and speed had to take precedence over many questions of theory that arose, although each question was fully discussed and considered.

Accepting the fact that Mr. Shaw states, that some wells yielded a minimum of 1500 times while others yielded 2000 times their first day's production, this may be accounted for in several ways. The many varying factors were all considered and no value was placed on a projected new well without considering its location, its proximity to other wells, sand thicknesses, and every geological condition, and these were also checked out to the ultimate production per acre, and per acre-foot of sand thickness, and the curve shown on page 527 is a close index to what may be expected for ultimate production from an average well of given initial production, as outlined.

The curve, to our mind, shows a wonderfully even diminishing decline, as the check figures in the table on page 530 indicate. It was deemed only fair to accept the production figures as obtained, listing the wells with no production, while several others were gushers, and in new territory where such would never be expected and have never been equalled in the further drilling of that field. The curves are all constructed from the best data obtainable, and we preferred using them with the slight irregularities at the second, fifth, and sixth years, rather than figuring empirical formulas.

It could not be expected that the heavy oils of Kern, Coalinga, and McKittrick would give the same curves as those from Santa Maria and the lighter oils of Southern California.

The drilling well data plotted in Fig. 4 were gathered from actual records, and the sharp upward curve between 2850 and 3000 ft. is accounted for by the fact that these wells were drilled partly rotary to

* Received April 29, 1918.

about 2500 ft. and finished by standard rig; they were included among the standard drilling data because some were started standard through the upper boulder formation, and then sunk by rotary to the then economic point of rotary drilling. We believe that since that time the rotary has made much better records.

Fig. 8 is not theoretically cut off at the 20-bbl. mark, but only for clearness in the print; it may be noted that all lines radiate from zero and would give values down to the zero point.

We do not agree that the main factors of our work are "production records and cost statistics,' for there were no operating costs that were directly applicable to this method. In the completed records of the properties appraised, every known factor was observed, and the geology, sand thicknesses, water conditions, well spacing, present operating conditions, equipment, location, and surroundings, were all duly considered, and each played an important part in determining and apportioning the well values. After that, the production curves were applied. Costs were worked out and standardized in the process of the work and are shown in the fullest detail in the report of every property; each property was made a problem to itself and treated as such.

The final summary sheets showed the acreage, drilled and undrilled, production of drilled portion, future, and ultimate per acre, together with operating and development costs, and value per acre. These results were also plotted to check for discrepancies, and showed acceptable uniformity.

Water Surfaces in the Oil Fields

BY MARCEL R. DALY, SEATTLE, WASH.

(New York Meeting, February, 1918)

(A contribution to the study of the conditions of equilibrium of the "free surface" of a water body inclosed in a porous medium.)

IN a recent paper on Geologic Structure in the Cushing Oil and Gas Field, Oklahoma,[1] Carl H. Beal has pointed out some interesting peculiarities in the distribution of the hydrocarbons and the disposition of the "planes of separation" between the oil and the water (water surfaces). Mr. Beal's principal statements on this matter may be summarized as follows:

I. In every important dome in the Cushing field, which has not been complicated by folding along its sides, the oil area in each of the three oil and gas sands studied (Layton, Wheeler and Bartlesville) apparently extends farther down on the long axis of the dome than it does on the steeper sides. The result is that water is encountered at a lesser depth below datum plane (sea level) on the steep sides of the dome than along the ends where the beds are more gently tilted.

II. In the Layton and Wheeler sands (to which the detailed study of water surfaces has been almost entirely confined), the water surface is not level, but dips at a gentle angle (maximum dip 100 ft. to the mile) away from the center of the structure. This inclination existed prior to development, and it has been rendered greater by the rapid extraction of oil and gas.

To these statements, the following observations are added: The dominant structural feature in the Cushing field is a broad north and south anticlinal fold, along whose axis the domes are distributed (Fig. 1, p. 897), and the more important oil areas in each sand lie on the west side of the field. In many cases, gas has been forced to the east side of the structure, sometimes as far as the water line.

From the distribution of the oil and gas bodies, Mr. Beal concludes that the hydrocarbons in this region probably migrated from the west or the northwest.

It seems as if these different features would be susceptible of some

[1] *Trans.* (1917), **57**, 894.

mechanical interpretation, and the writer wishes to develop here briefly his views on the subject.[2]

At first, we may dispose of a possible objection. The propriety of likening the flow of underground waters to the flow of surface waters through pipes or channels, has been sometimes questioned. It is obvious that most of the formulas, and especially the "coefficients" used in practical hydraulic engineering for free-water flow, could hardly be expected to apply to a liquid flowing through a porous medium. Such formulas are merely a theoretical framework on which are hung the result of experiment, and whenever the conditions of experiment become different, the formulas may only yield misleading results. On the other hand, it cannot be denied that a surface flow and an underground flow are phenomena of the same order. As Slichter remarks,[3] "the water moves in the underground current for the same reason that water moves in the surface streams," and the general law of motion, in both cases, is grounded on the same fundamental principles. Bernouilli's Theorem, upon which hinges the whole fabric of hydromechanics, is simply an application of such principles; and wherever the assumptions on which this theorem is further based can be admitted (steady and non-sinuous flow of a perfect fluid), the theorem itself may be applied. In most cases, conditions would permit such an application to underground flow as well as to surface flow, within sufficient limits of approximation, and the close analogy of both groups of phenomena becomes apparent.

A second observation bears on the nature of the surface of equilibrium of a liquid, whether it be a free liquid or a liquid inclosed in a porous medium.

Whenever a free liquid is at rest and its free surface (or the surface which is in contact with a gas or vapor) is submitted to uniform pressure —for instance, atmospheric pressure—this surface is horizontal. And the same is true of a liquid inclosed in a porous medium, provided we should consider as "free surface" the upper surface of the saturated zone. In both cases the free surface is an equipotential surface and its form is determined by the condition that at every point it must be normal to the lines along which the material particles of water tend to travel following the direction of the most rapid potential fall (lines of force). Here, this direction is vertical, the only force acting on the particle being the force of gravity; hence the equipotential surface is horizontal.

There may be instances, such as illustrated in Fig. 1, in which the

[2] At the time this paper is written (October 1917), *Bulletin* No. 658 has not yet been issued by the U. S. Geological Survey, and Mr. Beal's abstract is the only source of information available to the writer in regard to the special features presented by the water surfaces in the Cushing field. Therefore, the conclusions presented here are subject to revision, in so far as they would conflict with some fact unknown.

[3] C. S. Slichter: The Motions of Underground Waters. *U. S. Geological Survey Water Supply Paper* No. 67 (1902), 17.

pressure above the liquid would vary from one point to another. If the pressure in A be the atmospheric pressure, for instance, and the pressure in B be greater than atmospheric, the free surface in both parts of the container would no more be on the same level; cd, in B, would be lower than ab, in A. Conditions may be imagined in nature where the same result would obtain. Such would be the case in a flexed sand stratum (Fig. 2), where the gas pressure may be greater in B than in A. But in both instances, the surfaces ab and cd, considered individually, would be horizontal. The horizontality of the free surface of a liquid in contact with a gas or vapor, whether it be a free liquid above ground or an underground liquid inclosed in a porous medium, becomes thus a direct consequence of the state of rest; it is the expression of static equilibrium.

Conditions are entirely different when the liquid, whether free or not, is in a state of motion. The free surface of a body of water in steady motion, which is the condition most generally to be considered, will be normal at any point to the resultant of (1) the force required to reduce a particle of water at that point to rest or to uniform motion in a straight

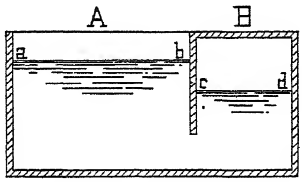

FIG. 1.

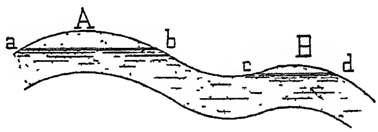

FIG. 2.

line, and (2) the force of gravity on the particle. The first force would be inclined,[4] whereas the second is vertical. Hence, the resultant would be inclined also, and so would the free surface at that point. The differential equation of the longitudinal profile of such a surface shows it to be a curved surface, which becomes a plane when the flow is uniform. The fact that the body of water is inclosed in a porous medium would introduce an additional set of conditions, due to the resistance against motion of this intervening medium, but the resulting "free-surface" would still remain a curved surface and the same conclusions would obtain. Thus, the characteristic of the free surface of a liquid in motion, whether free or inclosed in a porous medium, is its non-horizontality, or its continuous slope.[5]

The peculiarities recorded by Mr. Beal in the Cushing field, and heretofore summarized, imply the existence of gradually sloping water surfaces in open channels or incompletely filled conduits; and such conditions

[4] Unless the direction of the motion should be vertical, which is a case limit and is not to be considered here.

[5] The presence of a sheet of oil resting on the surface of the water would not change the scope of these conclusions.

would, in their turn, imply the motion of the underlying water bodies. The conclusion is that, in the Cushing field, the "edge waters" on which the oil and gas rest are presumably in a state of motion, and the following observations are offered as a consequence of this preliminary remark.

The phenomenon of "backwater" is well known in hydraulics. It occurs when an open channel is obstructed by a dam or weir. If the water is flowing in the channel with uniform motion previous to the construction of the weir, the raising of the weir will cause the water to

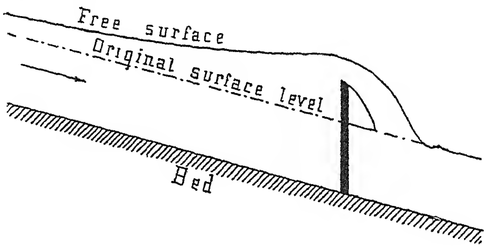

Fig. 3.

back upstream, increasing the depth in the direction of flow (Fig. 3). The same phenomenon may be observed, on a reduced scale, in a shallow stream, where the bed is strewn with cobbles or boulders. Whenever the water encounters an emergent boulder, it rises against its upstream face, and, dependent on conditions, it may either flow over it or simply turn around it. If the boulder is not submerged (Fig. 4), as between boulders, and downstream from them, the stream maintains its normal depth, the line of intersection *abcde* of the obstacle with the water surface

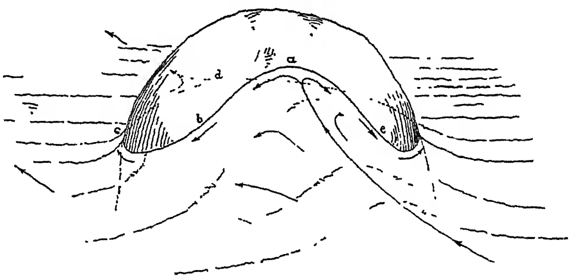

Fig. 4.—(The arrows mark the direction of the current.)

in front of it decreases in height on both sides of the stone, its highest point *a* being roughly located under the crest of the latter; and the water surface is seen to dip away from the center of the stone, especially in the upstream direction and on both flanks. Where the rush of the water is sufficient and the dimensions of the boulder are not too large, the obstacle may be entirely submerged. In this case, provided the amount of submergence keeps under certain limits, the water surface above the stone is again seen to dip in every direction away from the crest.

In both preceding instances (dam and boulder) the channel is sup-

posed to dip in the direction of the current, and the motion of the water is due to gravity. But there are cases in nature where such conditions are reversed; *i.e.*, where the current runs up dip and against gravity. For instance, one may have observed the waves breaking on a gently rising sand beach. Whenever the wave collapses, the waters are thrown forward and dash, for the most part, upshore. They form a sheet that spreads ahead and laterally. If these ascending waters encounter a shingle or a large pebble, they will rise against the obstacle, exactly as in the two previous instances, and the same deformation obtains for the free surface of the liquid. The rule is thus a general one, as far as observation goes; and it is further confirmed by mathematical analysis.

Let us turn now to the Cushing field and consider, for instance, the sketch map showing the generalized structure of the Layton sand.[6] If the oil and gas bodies have migrated from the west or northwest, as Mr. Beal admits, then the anticlinal fold, which cuts the field with a north-south trend and along whose axis the domes are distributed, must have acted as an obstacle in the path of the transporting waters flowing through the sand from this same western or northwestern direction. The sand stratum through which this flow has taken place would have to be considered, from the standpoint of hydraulics, as the equivalent of an "open channel" or an "incompletely filled pipe," at least in the neighborhood of the field. This is evidenced by the disposition of the water surfaces themselves, on which the oil and gas rest, and the variableness of their slope, that has been rendered greater by extraction since development has begun. Thus, the conditions would be similar to those which would be met if a dam, provided with a series of contracted weirs, were erected across a wide and shallow river, or if a line of boulders were deposited in the bed of a shallow stream, athwart its course. The series of peculiarities noted by Mr. Beal would be the natural consequence of such a disposition. The water would have to rise to a higher level against the steeper flanks of the domes than against their lower extremities or at points where the stream is permitted to cross the structure through "cols" or depressions. In consequence, water would be found at a lesser depth, under datum plane, on the steeper sides of the domes than farther down along their axis. Further, the water surfaces would have to be inclined away from the center of the anticlinal folds, exactly as they are in the case represented in Fig. 4., and for the same reasons.

The increase in slope of the water surfaces that has been noted after the rapid extraction of gas and oil in the field, would have to be traced to the decrease of the counter pressure, resulting in a suction and a consequent increase in the velocity of the water current. The slope of the free surface of a water body in the state of motion is a function of its velocity. An increase in the velocity of the current would necessarily fol-

[6] *Trans.* (1917), **57**, 897.

low the rapid decrease of counter-pressure resulting from the escape of the gas, or the reduction in volume of the fluids that rest on the water itself.

The velocities in such a body of moving waters would not be the same everywhere. The velocity would reach a maximum wherever the current passes freely across the folds; and would reach a minimum where the edges of the stream abut on the protruding parts of the structure, such as the domes, against which the current would be deflected, or at points where the structure of the ground would induce the formation of local eddies. Such places would be the most favorable ones for the accumulation of the transported materials, oil and gas, and these primary deposits would, for the most part, face an upstream direction; *i.e.*, they would mostly be found on the western side of the anticlinal fold. Moreover, when laid down, these transported materials would settle according to density. The oil would largely remain where first deposited, whereas gas would diffuse through the sand. It would tend to reach the higher places (the crest of the folds, the summit of the domes, etc.) but, at the same time, it would invade those parts of the sand stratum that are free of water and where oil has no access, especially on the reverse side (eastern side) of the structure, facing the downstream direction. Gas may then accumulate in such places as far as the water line.

A question may be raised here. How is it possible that the transported materials, especially the oil which remains in contact with the upper surface of the water, would reach a state of rest when the underlying waters are still in a state of motion and remain so permanently? This may be readily answered. The writer has already pointed out in a preceding paper[7] that for each insoluble material transported by a current flowing through a porous medium, whether this material be heavier or lighter than the transporting liquid, there is a certain velocity limit under which the transportation ceases to be possible and deposition ensues. This result is essentially due to the difference of density between the two materials, the transporting and the transported, and to the resistance against movement of the porous medium. The resulting action may be directed either down or up, depending upon whether the transported material is heavier or lighter than the transporting liquid. Now, the velocity of an underground flow is generally very low when the origin of the movement is simply due to a static head, as would be the case today, in the present instance, and this velocity would easily fall under the velocity limit corresponding to oil and gas deposition; so that oil would be at rest upon the moving sheet of water simply for the reason that the motion of the latter would have reached a stage at which it can no more transport the oil, exactly as a sluggish stream flows over the gravels of its bed which it cannot "scour" any longer. This remark leads us to a further conclusion. It is obvious that if the

[7] *Trans* (1917), **56**, 765.

present velocity of underground flow does not permit any more oil transportation, conditions must have been somewhat different in the past, when the hydrocarbons were being collected and accumulated. For reasons given elsewhere,[8] the writer considers it very doubtful that the pressure due to a static head alone could ever, under normal conditions, be adequate to produce the velocity required for transportation. We are thus brought to consider the intervention of some other force, whose action would be dynamic rather than static, and the probability of some intimate connection between petroliferous accumulation and diastrophic deformation becomes once more apparent.

Conclusions

I. In the Cushing field, the "edge waters" on which the oil and gas rest are presumably in a state of motion; the main direction of flow proceeding from the west or northwest.

II. The peculiarities pointed out by Mr. Beal—such as: the variation in the level of the water surfaces, which are found higher along the steep flanks of the domes and further down on their long axes; the slope of the water surfaces, away from the axis of the structure; the localization of the more important oil areas on the west side of the folds; the concentration of some gas bodies on the eastern side, as far as the water line, etc.—would be as many expressions of such a state of motion.

III. The disposition of the water surfaces noted in the Cushing field may be encountered elsewhere, but there is no apparent reason why this disposition should be considered as a general rule. These forms depend on a state of movement which may not always exist, although such a condition is probably more frequent than is generally admitted. On the other hand, the peculiarities themselves bear an intimate relation to each other; they are parts of a system, and wherever one of them is noted, the others are likely to be found. This consideration may have some practical importance.

IV. The water surfaces would not be planes, but surfaces with a double curvature, as the motion would be non-uniform.

V. The increase in the slope of the water surfaces resulting from the rapid extraction of oil and gas could not be expected to remain permanent. Eventually, this slope would have to be reduced in proportion as the extraction itself declines. But the general advance of the water bodies would probably be final.

VI. The facts observed and the conclusions heretofore set forth, suggest, by way of inference, that, in the past, the cause of motion cannot be ascribed to static pressure alone, as the resulting velocity of flow would not have been sufficient to promote the concentration of the hydrocarbons. The writer is once more of the opinion that the real source of this motion is to be found in diastrophic deformation.

[8] *Trans.* (1917), 56, 737.

Age of the Oil in Southern Oklahoma Fields

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(New York Meeting, February, 1918)

Introduction

Since the opening of the Wheeler oil and gas field in Carter County and the discovery of oil near Lawton, Comanche County, Okla., in 1904, interest has been aroused regarding the origin of the oil in the Permian "Red Bed" region which lies between the Wichita and Arbuckle Mountains on the north and the Red River on the south. The later development of the Healdton, Loco, Duncan, Fox, and Graham fields south and west of the Arbuckle Mountains has brought the region into prominence. Recent discoveries of Ordovician and of Pennsylvanian fossils in wells in the Healdton field and of Pennsylvanian fossils in the Fox and Graham fields are of such importance from a scientific and a commercial standpoint that the occurrences and the problems arising therefrom are here briefly described.

Producing oil and gas sands in the southern Oklahoma fields, with the exception of those in the Cretaceous and underlying rocks in the vicinity of Madill, Marshall County, are associated with the Permian "Red Beds" or with the underlying Paleozoic strata. In the two fields farthest south of the Arbuckle Mountains, Healdton and Loco, production has been entirely confined to sands at depths of 700 to 1400 ft. (213 to 416 m.) and only recently has a producing sand as deep as 1860 ft. (567 m.)[1] been encountered. These sands are found near and below the base of the red rocks and were supposed by Wegemann and Heald[2] to belong in large part to the basal Permian, Wichita formation, or to the immediately underlying formations. Fossils in the blue shales and in the limestones associated with the deeper sands now prove them to be Pennsylvanian and all the producing sands at Healdton are found to be of this age. In the fields nearest the Arbuckle Mountains, the Wheeler sands at a depth of about 700 ft. (213 m.) appear to be of Permian age,

[1] The general altitude of the country varies from about 850 ft. (259 m.) at Healdton to 1150 ft. (350 m.) at Duncan. (A sand of Ordovician age has been discovered at a depth of 2700 ft. since the above was written.)

[2] C. H. Wegemann and K. C. Heald: Healdton Oil Field, Carter County, Oklahoma. *U. S. Geological Survey Bulletin* 621B (1915).

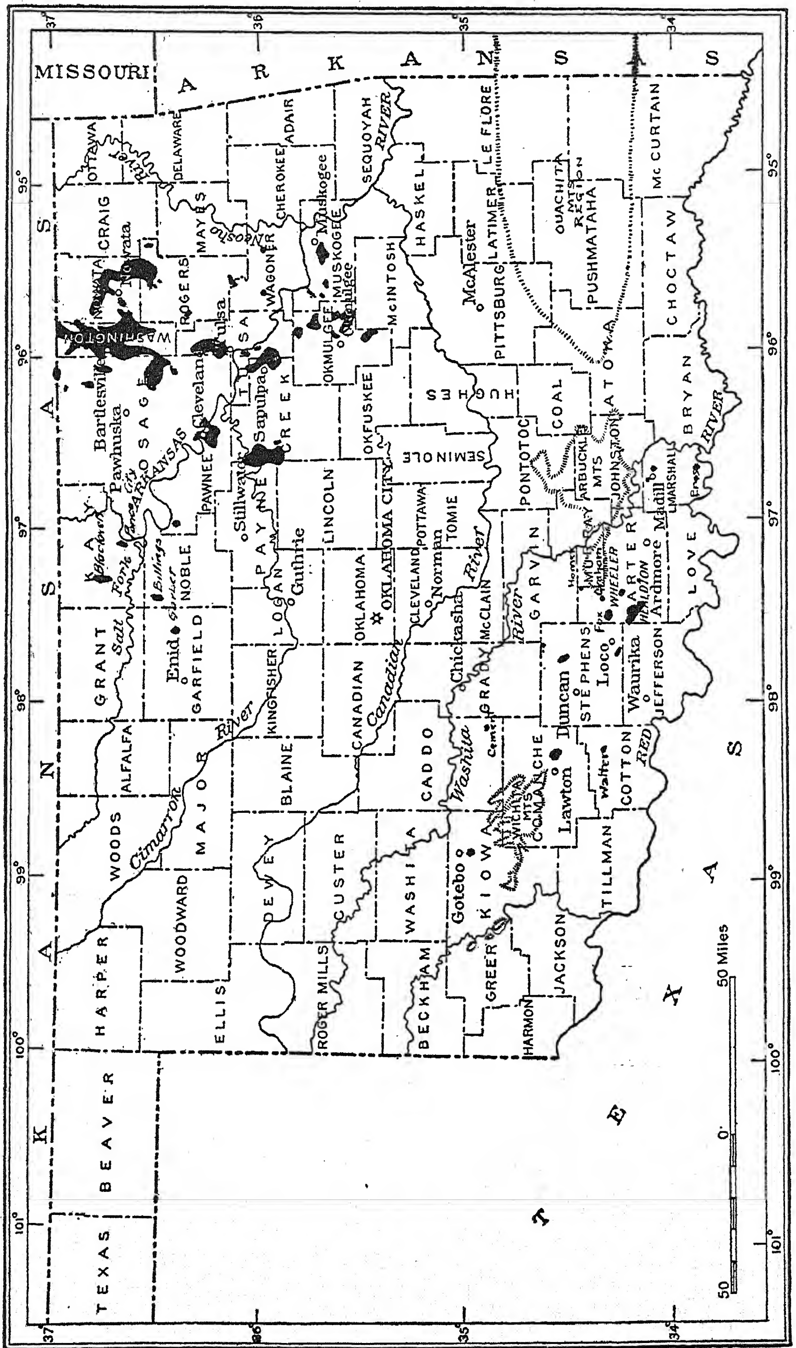

FIG. 1.—INDEX MAP OF OKLAHOMA SHOWING OIL AND GAS FIELDS SOUTH OF THE ARBUCKLE AND WICHITA MOUNTAINS AND MANY OF THOSE IN THE REMAINDER OF THE STATE. (*From U. S. Geological Survey, Bulletin No. 621.*)

the Fox sands at depths of about 2000 ft. (609 m.) are definitely pre-Permian, and the Graham sands are both Permian and Pennsylvanian, while the Lawton field has three Permian sands, the deepest of which is 800 ft. (243 m.) below the surface.

Geologic History

Southern Oklahoma comprises the Wichita, Arbuckle, and Ouachita Mountains (Fig. 1), the "Red Bed" country south of the first two mountain ranges, and the Cretaceous sand and limestone country southeast of the Arbuckles and south of the Ouachita Mountains.

The geological history of southern Oklahoma may be deciphered as far back as pre-Cambrian time for granite of this age formed the surface on which were deposited sandstones, limestones and shales (limestones predominating) of Lower Paleozoic age. About 8000 ft. (2438 m.) of sediments ranging in age from Middle Cambrian to Devonian are found in the Arbuckle Mountains. While deposition of shales and some limestones took place over part of this region in Mississippian time, the great thickness (10,000 ft. or more) of blue shales which occur on the flanks of the Arbuckle Mountains were deposited unconformably on the older sediments during the Pennsylvanian period. Following the mountain-building movement at the close of the Pennsylvanian, about 2500 ft., or more, of Permian red sandstones and shales with basal limestone conglomerates were laid down on the south and west sides of the Arbuckle Mountains. After the peneplanation of the region, Cretaceous sandstone beds were deposited southeast of the Arbuckle Mountains.

Diastrophism

Diastrophism in the region is connected with two disturbances, one in the late Paleozoic, the other in mid-Tertiary time.

The first disturbance was a continuation of the Appalachian mountain-building movement west of the Mississippi River. It commenced with the "Ouachita disturbance" of Schuchert in the Ouachita and in the Arbuckle Mountains during the close of the Mississippian, at which time the major Arbuckle uplift must have taken place. A second folding, the Appalachian revolution, at the close of the Pennsylvanian, further elevated and folded the Wichita, Arbuckle, and Ouachita Mountains, the Criner Hills and the buried Healdton Hills, to be referred to later. It is not improbable that this Appalachian revolution with the elevation of the Paleozoic geosynclinal prisms gave rise to the numerous anticlines of small vertical displacement which have produced so much petroleum in Oklahoma and Kansas north of the Arbuckle Mountains. In the closing stages of the Appalachian movement, the Permian and underlying

sediments were folded into their present attitude, giving rise to the Healdton, Loco, Lawton, and other anticlines. The location of the Healdton uplift was above the buried Healdton Hills. In some cases, the younger anticlines may have been formed over uplifts of late Pennsylvanian age, but in the majority of cases the anticlines were formed where there had been no late Pennsylvanian uplift.

The second disturbance, during the late Miocene (?), gave rise to the anticlines of small lateral extent and small displacement in the Cretaceous of southeastern Oklahoma and north Texas and to the Sabine uplift in Louisiana. On the peneplain developed after this uplift were laid the gravel deposits, consisting of quartz and chert pebbles, which are found throughout northern Louisiana and east Texas.[3]

Permian "Red Beds"

Forming a marked lithologic contrast to the older Paleozoic limestones and to the blue shales and occasional sandstones of the Pennsylvanian in and around the Arbuckle Mountains, the Permian sediments on the south and west of these mountains are composed at the base of limestones, limestone conglomerates, ferruginous and asphaltic sandstones, overlain by green and yellow sandstones and clays with a very thick series of red clays and sandstones and occasional selenite-bearing clays at the present top. Over 1600 ft. (487 m.) of red beds are recorded in some well logs.

Against the Arbuckle and Wichita Mountains, the Permian basal limestones, dipping away from the mountains at angles of 6° to 8°, rest on upturned and truncated older rocks ranging in age from pre-Cambrian to Pennsylvanian. The unconformity can be traced from the Arbuckle Mountains to the Criner Hills, but at the latter locality, near Brock, the unconformity becomes very slight.

A complete Permian section, as compiled from all the data available, gives the stratigraphy as follows:

Top	400+ft.	Red clay forming western prairies.
	550+ft.	Red sandstone.
	70 ft.	White calcareous sandstones and yellow selenite-bearing clays (at Fox).
	600+ft.	Red sandstone, upper beds being resistant to erosion.
	300+ft.	Pale greenish, yellowish and red sandstone (at Healdton).

[3] These gravel deposits are probably the peneplain equivalent of the Pliocene Citronelle formation in Louisiana (G. C. Matson: Pliocene Citronelle Formation of the Gulf Coastal Plain; E. W. Berry: Flora of the Citronelle Formation. *U. S. Geological Survey Professional Paper* 98L (1916)) and of the Lissie gravel of Texas (A. Deussen: Geology and Underground Waters of the Southeastern Part of the Texas Coastal Plain. *U. S. Geological Survey Water Supply Paper* 335 (1914), 78).

Base 80 ft. Basal limestone conglomerate, limestone, limonitic calcareous sandstone, forming foothills of. Arbuckle Mountains.

Total 2000+ft.

Conditions of deposition of the Permian are not well understood. It has been argued that the red color represents maturely weathered material in which the oxide of iron was dehydrated before deposition.[4] On the other hand, evidences of contemporaneous life consists of bones of land animals including amphibians and primitive reptiles, fish remains including sharks' teeth,[5] leaf impressions and silicified wood, the latter being especially abundant near the base of the formation. The sediments themselves, with the exception of the beds of almost pure limestone at the base of the formation near Poolville (Elk) and Woodford, and of arkose derived from the Tishomingo granite, exposed near Brock, show abundant cross-bedding, current marks, and both normal and torrential ripple marks, indicating shallow water or subaerial deposition. Broad flood plains with intermittent, overloaded streams transporting sand and clay from the uplands on the north, occasional playa lakes and incursions of a shallow sea, with a climate such as could support a limited tree growth on both the uplands and the flood plains, are supposed to represent conditions during Permian deposition.

Sources of Petroleum

Life of such a character as could give rise to accumulations of petroleum was entirely absent from the region during Permian deposition and it is therefore obvious that the petroleum now found in the Permian rocks must have been derived from some pre-Permian source. The quality of Permian oil is in general poorer than that of Pennsylvanian oil owing, doubtless, to contamination and deterioration by sulphur-bearing waters during irrigation.

Bitumen has for a number of years been mined in the Arbuckle Mountains in the vicinity of Gilsonite and of Dougherty, Murray County, and "shows" of heavy oil have been found in wells drilled in the older Paleozoic rocks to such an extent that further drilling is now being carried on. As described in the Tishomingo folio,[6] bitumen has been mined in the Franks conglomerate (Pennsylvanian), in the Viola limestone (Ordovic-

[4] The origin of the red color is discussed in the following references:

C. W. Tomlinson: The Origin of Red Beds, *Journal of Geology* (1916), **24**, 153–179, 239–253.

C. H. Wegemann: Anticlinal Structure in Parts of Cotton and Jefferson Counties, Oklahoma. *U. S. Geological Survey Bulletin* 602 (1915), 20–24.

[5] The animal and fish remains have been found south of the region under discussion.

[6] *U. S. Geological Survey, Folio* No. 98 (1903).

ian), and in both the middle and upper sandstone members of the Simpson formation (Ordovician). That the bitumen was apparently introduced into these rocks before late Pennsylvanian time is shown by the presence of boulders of bituminous Simpson formation (Ordovician) sandstone in the Franks conglomerate (Pennsylvanian).[7]

Bitumen also occurs in abundance in certain horizons of the Glenn formation (Pennsylvanian) south of the Arbuckle Mountains. Quarries have been opened in vertical beds of bituminous sandstone of this formation a mile south of Woodford and also 5 miles southwest of Ardmore.

Production may be expected from the petroleum-bearing sands of the Glenn formation when these sands are found in an unoxidized state beneath gently folded anticlines. It is a question, however, whether oil and gas in commercial quantities can be expected from the Ordovician sands under the same conditions on account of the degree of metamorphism which they have undergone.[8]

Age of the Strata Beneath the Oil Fields

Loco

During the examination of the Duncan, Loco, and Healdton fields by C. H. Wegemann in 1914,[9] Pennsylvanian fossils were found in some of the deeper wells in the Loco gas field and Wegemann suggests that the contact between the Permian and Pennsylvanian lies above the limestone which is found at depths of 860 to 1000 ft. (262 to 304 m.) below the surface.[10] The most productive gas sand (at 700 to 800 ft.) may be at the base of the Permian.

Duncan, Lawton, Wheeler

Although no fossils have been reported from the Duncan or Lawton fields, Wegemann believes that Pennsylvanian rocks underlie both fields, possibly at a depth of 1825 ft. (556 m.), in the former and 1165 ft. (355 m.) in the latter. At Lawton, the absence of any exposures of Pennsylvanian rocks and the presence of Cambro-Ordovician strata dipping 4° southeast at a distance of only 5 miles northwest of the field make it probable that pre-Carboniferous, and possibly Simpson or Viola petroleum-bearing strata underlie the field and that from them the petroleum leaked into the Permian beds.

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[7] *Idem*, 8.

[8] David White: Some Relations in Origin between Coal and Petroleum. *Journal of the Washington Academy of Science* (1915), **5**, 189–212.

[9] *U. S. Geological Survey, Bulletins* 621 *b*, *c*, and *d*, respectively (1915): (*b*) C. H. Wegemann and K. C. Heald: Healdton Oil Field, Carter County, Oklahoma. (*c*) C. H. Wegemann: Loco Gas Field, Stephens and Jefferson Counties, Oklahoma; (*d*) C. H. Wegemann: Duncan Gas Field, Stephens County, Oklahoma.

[10] *Idem, Bulletin* 621 *c*, 35.

Permian strata at Wheeler[11] extend to a depth of about 900 ft., th oil and gas sands occurring at depths of between 700 and 900 ft. (213 t 274 m.). The great thickness of blue shales, barren of petroleum, en countered in deep wells in the field indicates that the strata beneath th Permian are probably of Pennsylvanian, Glenn formation, age. It doe not appear to be possible to correlate the logs of the deep Wheeler well with those of the Fox wells.

Fox, Graham

In the Fox and Graham fields in T2S, R3W and T2S, R2W, respectively, Pennsylvanian fossils have been found by the writer in cuttings from the wells. Crinoid stems have been found in five wells and additional fossils in two wells which have been identified by Dr. G. H. Girty of the U. S. Geological Survey. Crinoids only were noted in Gypsy Oil Co., Mattie Morris No. 1, sec. 28, T2S, R3W at a depth of about 1800 ft. (548 m.); in Plains Oil Co., Bentley No. 1, same section, depths 1956 and 2010 ft. (596 and 612 m.); in Okla-Fox Oil Co., Airington No. 1, sec. 7, T2S, R2W, depth about 2550 ft. (777 m.). Fragments of a small Rhombopora (possibly R. Lepidendroides), and possibly a Fenestella brace, were found in material from Gypsy Oil Co., Mattie F. V. Morris No. 1 (Mattie Morris No. 2), sec. 29, T2S, R3W, depth 1930 ft. (588 m.), and the following fossils were identified by Dr. Girty from a limestone passed through in the Creston Oil Co., G. W. Chaffee No. 1, sec. 2, T3S, R3W, from 1400 to 1430 ft. (426 to 436 m.).

Syringopora multattenuata.
Filistulipora carbonaria.
Productus cora.
Fusulina related to *F. cylindrica.*
Bryozoa belonging to the genera *Stenopora* and *Polypora.*
Crinoid segments.

Heavy, asphaltic oil (19.4°–22.0° G. Bé.) is found in small quantities in the Graham field, Pennsylvanian sands producing at a depth of 2590 to 2725 ft. (789 to 830 m.) in sec. 7, T2S, R2W and a Permian sand producing at a depth of 1650 ft. (503 m.) in sec. 18 of the same township. The deeper oil is of slightly better grade than is the shallower.

Fox has produced enormous quantities of gas from the center of the anticline in sections 28–29, T2S, R3W, and some oil near the crest of the structure in section 29 and on the north side in section 20. Production is from Pennsylvanian sands, some of which may be continuous under the field, but many of which are in the form of lenses, at depths of 1400 to 2100 ft. (426 to 640 m.). No petroleum has been noted in the "Red Beds" at Fox although the structure in these beds appears to be almost

[11] J. H. Gardner: The Oil Pools of Southern Oklahoma and Northern Texas. *Economic Geology* (1915), **10**, 422–434.

identical with that in the underlying Pennsylvanian rocks. In the next anticline to the west along the Wheeler-Fox line, small production is expected from the Permian at 1100 ft. (335 m.) (30 ft. above the base of the "Red Beds") in sec. 13, T2S, R4W and farther west an oil sand has been found at a reported depth of 520 ft. (158 m.) in sec. 36, T1S, R5W on the Velma anticline. The oil in the Fox pool is of a better grade, 31.4°–34.0° G. Bé., than that in the Graham field although the principal producing sand appears to be the same in both fields.

Healdton

In cuttings from wells in the Healdton field, which has a daily production of about 65,000 bbl. of oil with an asphaltic base, fossils of Pennsylvanian and also of Ordovician age have been found by the writer. The distribution of the wells and the depths from which the fossils have come prove that the field is composed of a cover of Permian "Red Beds" which do not contain petroleum in commercial quantities, conformably overlying Pennsylvanian (Glenn formation ?) blue shales, thin limestones, and irregular sandstones from which the production comes. Unconformably beneath the Pennsylvanian rocks is a mass of Ordovician limestones and shales which may have the form of a closely folded anticline. This old ridge may be called the buried "Healdton Hills," as during early Pennsylvanian deposition it must have resembled the Criner Hills of today. The Healdton Hills, together with the Criner Hills which are structurally similar,[12] must have been formed at some time between the close of the Ordovician and the beginning of the Pennsylvanian—possibly at the time of the late Mississippian movements in the Ouachita and Arbuckle Mountains[13]—and must have been subjected to considerable erosion before Pennsylvanian deposition in the region.

A list of the wells from which fossils have been secured follows (see

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[12] The Criner Hills are mapped by J. A. Taff: Preliminary Report on the Geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma. *U. S. Geological Survey, Professional Paper* 31 (1904). There is a remarkable arrangement of anticlines in southern Oklahoma in northwest-southeast lines. One of these lines, in Marshall County, Oklahoma, and Grayson County, Texas, passes through the bend in the Red River near Shay and Preston and contains the Preston anticline and Enos gas field (in the Cretaceous Trinity sand). Two other lines seem to diverge from the Criner Hills, one passing through Wheeler and Fox and Velma, the other through Healdton and Loco. The Graham and Duncan structures may be on still another line. In the lines west of the Criner Hills the axes of the individual anticlines are *en échelon* to the general trend.

[13] It is possible that the movement was Lower Paleozoic and comparable to that which has been suggested by the writer in the case of the buried granite knobs of Kansas. *American Journal of Science*, Ser. 4 (1917), **44**, 146–150.

Fig. 2), the identifications being by Dr. E. O. Ulrich of the U. S. Geological Survey:

Pennsylvanian

Southwestern Pet. Co., Hartgrove No. 1, NW corner sec. 19, T4S, R2W (in white limestone), depth 1960 to 2055 ft. (597 to 626 m.).

Producers Oil Co., Jerome Watson No. 16, NE¼, SE¼, SE¼, sec. 15, T4S, R3W, depth 1200 ft. (365 m.).

Gates Oil Co., Lizzie Carnes No. 15, E side, NE¼, SE¼, same section, depth 1228 ft. (374 m.).

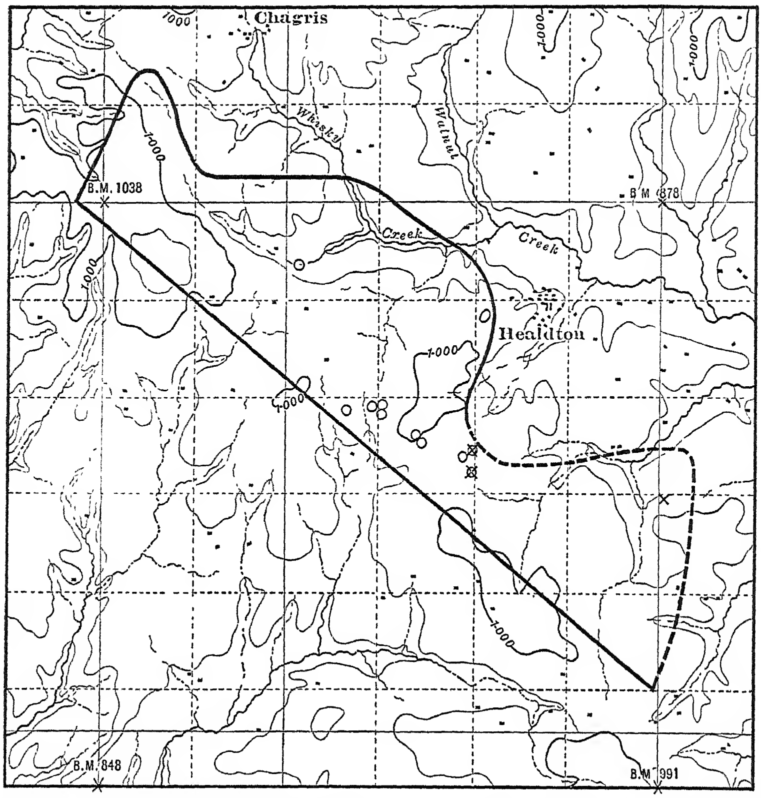

FIG. 2.—MAP SHOWING THE LIMITS OF PRODUCTION IN THE HEALDTON OIL FIELD. THE LOCATION OF THE WELLS FROM WHICH FOSSILS HAVE BEEN OBTAINED ARE GIVEN, A CROSS INDICATING PENNSYLVANIAN, A CIRCLE ORDOVICIAN FOSSILS. NOTE THE "DRY HOLE" LINE WHICH BOUNDS THE FIELD ON THE SOUTH.

Ordovician

1. Hamon and Colcord, D. O. Coffey No. 11, center sec. 15, T4S, R3W, depth 1375 to 1400 ft. (419–426 m.).
2. Producers Oil Co., Jerome Watson No. 11, E side SE¼ same section, depth 1550 ft. (472 m.).
3. Ruby Oil Co., Ruby-Ingram No. 2, SE¼, NW¼ same section, depth 1232 to 1235 ft. (?) (375 to 376 m.).

4. Magnolia Pet. Co., D. O. Coffey No. 19, NW¼, SW¼, NW¼, same section, depth 1184 to 1400 ft. (360 to 426 m.).

5. Scivally Pet. Co., Vernon Collins No. 9, SW¼, NW¼, NW¼, same section, depth 1192 to 1200 ft. (363 to 365 m.).

6. Bullhead Oil Co., A. Daney No. 14, NW¼, SW¼, sec. 4, T4S, R3W, depth 2470 to 2510 ft. (752 to 765 m.). (Production 48 bbl. 44° Bé oil 2716 to 2749 ft. (827.8 to 837.8 m.)).

7. De Sada Oil Co., Vernon Collins No. 5, SE¼, NE¼, NE¼, sec. 16, depth 1156 to 1239 ft. (352 to 377 m.).

8. Carter Oil Co., John Carter No. 1, S line, NW¼, NE¼, same section, depth 1100 ft. (335 m).

9. Producers Oil Co., Jerome Watson No. 16, NE¼, SE¼, SE¼, section 15, depth 1270 ft. (387 m.).

10. Gates Oil Co., Lizzie Carnes No. 15, E side, NE¼, SE¼, same section, depth ess than 1329 feet (405 m.).

Dr. Ulrich has identified the fossils listed below from (1), the horizon being in the lower third of the Simpson formation on the southern flank of the Arbuckle Mountains, about 1350 ft. (400 m.) beneath the base of the overlying Viola limestone in sections near Springer, Carter County.[14]

Plates and columnals suggesting Caryocystites and probably one or two other genera of cystids.

Bythopora n. sp.
Eridotrypa ? n. sp.
Orthis aff. orthambonites and tricenaria.
Plectambonites ? sp.?
Maclurea ? n. sp.
Aparchites sp.
Schmidtella sp.
Amphion cf. nevadaensis.

Limestone fragments from (2) were practically the same in lithology and faunal contents as (1), but contained an ostracod of undescribed genus. Lower Simpson is suggested by material from (4–7) and the same zone or possibly a higher one (upper Simpson) is indicated by crinoid or cystid columnals from (8–10).

The fossils were found in cuttings of blue sandy shale and of limestones and were in a number of instances (wells 4–10) so minute that they were found only by examining the fine cuttings with a high-power lens. Some of the Pennsylvanian fossils at Healdton occur in a very fine oolite.

In three wells (8–10), if the identifications of the "crinoid and cystid columnals" (which were most minute) are correct, production is from Ordovician sands, 109 ft. (33.23 m.) below where the fossils were collected in (8), 100 ft. (30.5 m.) below the fossil horizon in (9), and oil sands were encountered below the fossil horizon in (10) although this well

[14] S. Powers: Ordovician Strata beneath the Healdton Oil Field, Oklahoma, *Bulletin of the Geological Society of America* (1917), **28**, 159.

was abandoned.[15] No evidence favoring sands in the Ordovician rocks has been found in the well logs and there is very good evidence to show that the older rocks begin at or just beneath the lowest producing sand. In the A. Daney well in section 4, which is drilling at a depth of 3450 ft. (1051 m.) at the time of writing, "shows" of oil have been reported far below proven Ordovician rocks, but no confirmation of these reports is obtainable. If production is obtained in this well below 2500 ft. (762 m.) the oil will come from Ordovician rocks, but the possibility of downward migration from the Pennsylvanian will remain.[16]

A number of sands are productive in the Healdton field and while individual sands can be correlated in adjacent wells, no single sand can be traced over the field. The shallower sands, especially in the central portion of the field, at depths of 700 to 1000 ft. (213 to 304 m.), are known as the Healdton sands and produce black oil of gravity 27° to 31° Bé. In the Northwest Extension the shallow sands appear to merge into a single 100-ft. (30-m.) sand. In the Southeast Extension deeper sands, the deepest of which, with the exception of a lens at 1860 ft. (567 m.), is 1430 ft. (435 m.), are called by various names and yield green to black oil which is usually of slightly better grade than the oil from shallower sands.

Little is known of the buried erosion surface above the Ordovician limestones and shales. Basal conglomerates are not found, but fine bluish sands composed largely of limestone grains as seen in the cuttings appear to overlie the limestones, and it is in these basal sands and sandy limestones that a large percentage of the deeper production comes. Occasionally the basal sand is barren or missing and these places may be slight rises in the buried Hills. Relief is shown in the old erosion surface along the strike of the field from section 5 T3S, R4W to section 18 T4S, R2W of over 900 ft. (274 m.), or 180 ft. (54 m.) per mile if the slope were uniform (which is not the case). Across the strike it is not possible to give figures, but a far steeper surface gradient must exist (Fig. 3).

The importance of Ordovician limestones to petroleum geology is that the deep wells in the limestone will be dry and that deep sands are to be expected only on the edges of the field. The Ordovician rocks have, however, a greater significance, for they apparently determined the shape of the field (Fig. 2) which has a sharp southern boundary and three lobes, symmetrically arranged, on the north. A "dry hole" line exists on the south, toward which wells grow small and beyond which, with the exception of three or four four-barrel wells, all wells drilled have encoun-

[15] The cuttings were collected by the writer while the wells were drilling and before the oil sands were reached and the depths from which the material came are accurate to within a few feet.

[16] The A. Daney well was shot twice and is producing 48 bbl. of 44° Bé oil (very much lighter oil than any other in the field) from a sand at 2716 to 2749 ft. (827.8 to 837.8 m.).

tered either dry or salt-water sands corresponding to those which produce petroleum north of the line. This line may be explained as representing the south face of the Healdton Hills just as today an even line, interrupted by only two faults, represents the southern boundary of the Arbuckle Mountains in Carter County. If the Ordovician strata dip steeply south on the south side of the Healdton Hills, erosion would normally produce a steep, straight south face in hard limestones beneath soft rocks and a more or less undulatory upper surface in the main upturned mass, very possibly sloping gently north (Fig. 3). With the epeirogenic movements at the close of the Permian an uplift would be expected to act most effectively on a buried mountain mass and an isostatic readjustment would diminish the volume of the younger sediments on all sides of an older, buried mass; a movement of either kind producing the same effect: an emphasis of preëxisting topography in the younger rocks.

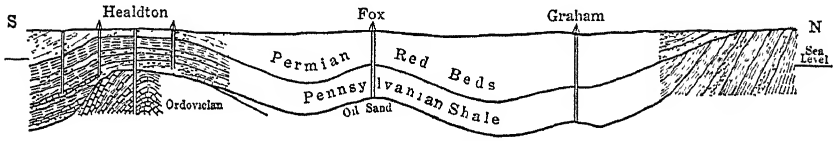

FIG. 3.—CROSS-SECTION OF THE HEALDTON, FOX AND WHEELER ANTICLINES SHOWING THE RELATION OF THE BURIED HEALDTON HILLS, COMPOSED OF ORDOVICIAN STRATA, TO THE OVERLYING PENNSYLVANIAN AND PERMIAN STRATA. SECTION DRAWN TO SCALE (TOTAL LENGTH 21 MILES) WITH A VERTICAL EXAGGERATION 4×.

CONCLUSIONS

Southern Oklahoma fields, with the exception of Fox and Healdton, yield petroleum from Permian strata, the petroleum probably having migrated from Pennsylvanian and possibly in part from older sands. In the Fox, Graham, and Healdton fields, oil is produced from Pennsylvanian sands. Deep tests have shown the absence of any deep petroleum sands at Wheeler and at Lawton, but deep tests have been lacking in the centers of the Loco and Duncan fields.

Healdton presents an example of a mountain-built, probably anticlinal, structure buried beneath sediments of both Pennsylvanian and Permian age, the older mass having determined the presence and the form of the uplift in the younger rocks. It has been shown that the Permian and Pennsylvanian are practically conformable at Healdton, as they are in the Fox and Graham fields on the north, but that the Pennsylvanian was deposited on an upturned mass of Ordovician strata. Oil has been found in only one well in the Ordovician rocks, if the evidence of well logs is accepted, and little Ordovician oil is to be expected. Production at Healdton will be practically confined to the top and sides of the old Healdton Hills in the irregular sands of Pennsylvanian age above the massive Ordovician limestones.

DISCUSSION

WALLACE E. PRATT, Wichita Falls, Tex. (written discussion*).—The age of the oil in the southern Oklahoma fields, Mr. Powers concludes, is Pennsylvanian, or in part, possibly, pre-Pennsylvanian. In a later paper,[1] he recognizes the Ordovician age of the small production from the Bullhead A. Daney, No. 14, in the Healdton field. But nowhere does Mr. Powers admit the possibility of oil of Permian age in southern Oklahoma. Yet shallow oil in the adjacent north Texas fields (Electra, Burkburnett, and Petrolia), which are generally conceded to be closely related to the fields of southern Oklahoma in geological aspect, may very well be of Permian age. Dr. Udden has already discussed this question,[2] noting the organic nature of the limestone outcropping near Electra, together with other evidence that organic material was present if not abundant, originally, in Permian rocks. The Permian rocks in north Texas seem to me, in fact, to be quite suitable in character to have given origin to the oil contained in them; and the oil in them seems to be just the class of oil one would expect, knowing beforehand the character of the oil in, and native to, the underlying Pennsylvanian.

Doubtless the exposed Permian beds in southern Oklahoma are less organic in nature than those across Red River in Texas; probably, as Mr. Powers thinks, all the oil so far obtained in southern Oklahoma is pre-Permian in origin; but in adjacent producing fields within the same geologic province, oil of probable Permian age is being obtained, and it seems quite possible that future development may be rewarded with oil of the same age in southern Oklahoma.

Are the developed fields of north Texas, like Healdton, as described by Mr. Powers, on folds superimposed on older, unconformable, "buried hills," the presence of which fixed the position of the folds in the later rocks, and is there here, as at Healdton, a comparatively shallow limiting depth beyond which petroleum is not to be sought? Unfortunately, the answer to these questions probably cannot yet be made with the secure basis Mr. Powers' data affords for his conclusions on Healdton. Certainly deep holes—more than 2000 ft. deep—have not been encouragingly successful in the developed north Texas fields. It is true, also, that limestone is encountered generally below the deepest producing horizons, and several observers have taken the evidence at places to indicate an unconformity over this limestone. There seems to have been no question as to the Pennsylvanian age of the rocks at the bottoms of all the deep holes drilled to date; however, even where unconformity is suspected. The presence of petroleum in north Texas below the deepest producing

* Received Jan. 12, 1918.

[1] Sidney Powers: The Healdton Oil Field, Oklahoma. *Economic Geology* (October-November, 1917), **12**, 594–606.

[2] J. A. Udden: Reconnaissance Report on the Geology of the Oil and Gas Fields of Wichita and Clay Counties, Texas. *University of Texas Bulletin* 246 (1912), 94.

sands, is, therefore, not unlikely, since farther south in Texas oil is now being obtained from the lowest beds of the Pennsylvanian.

Mr. Powers' data on Healdton is fundamental to any intelligent analysis of the petroleum geology of that field, but it is made public nearly four years after drilling started there, at a time when, apparently, the field is near to the beginning of its decline. Is geology really utilized by the petroleum industry to the extent we like to think? Or to the extent conclusions as important as those Mr. Powers is able to draw make its use seem justifiable? If so, would not the condition, for instance, that the deep production which is so valuable over large parts of Healdton cannot be expected in the very heart of the field, have become generally known long since? Possibly, indeed, all the companies employing geologists have known of this condition in the Healdton field for a longer time than the public. But I suspect that it would have been possible at a very recent date, to have interested more than one large, progressive operator in Healdton acreage, now condemned by Mr. Powers as of no promise for deep production, at prices based on the assumption that the deeper sands would produce there as elsewhere.

W. G. Matteson, Houston, Tex.—I think that Mr. Powers has given us some very valuable information on the Healdton field, which is of material interest in view of the fact that the Healdton field has passed Cushing in the point of production, and if not leading, stands second only to the new El Dorado field in the point of production of the oil in this country.

Mr. Powers says that the deepest producing sand at Healdton is 1860 ft. Within the last 3 or 4 months they have drilled to 2700 ft. there and found a sand which is producing very high-grade oil, if I remember correctly, about 42 gravity.

Another very important point brought out by Mr. Powers is the fact that the Pennsylvanian beds and the Permian beds are conformable according to his interpretation. He seems to have based his interpretation upon the gathering of a number of well logs and a very careful study of them, but it seems to me the information furnished by the well logs is really insufficient to justify such an important conclusion. In the first place, the difficulty of interpreting the line of demarcation between the Permian "Red Beds" of Oklahoma and the top of the Pennsylvanian is apparent, for the reason that sometimes the uppermost Pennsylvanian formation has a reddish phase and the line of demarcation is not very sharp.

Mr. Powers says that in the vicinity of the Arbuckle Mountains the basic Permian consists of conglomerate of limestone. As we proceed in a southerly direction, however, that conglomerate disappears and the base of the Permian consists generally of a reddish clay. In fact, the field evidence, as one makes a study at Healdton, indicates the greater probability of an unconformity between the Pennsylvanian and the Permian formations.

Extraction of Gasoline from Natural Gas as an Industry Allied to Production and Refining of Petroleum

BY FRANK. P. PETERSON, TULSA, OKLA.

(New York Meeting, February, 1918)

THE manufacture of gasoline by extraction or precipitation from the natural gases in which it is found, the present status of the industry, its past development and future extensions, offer a subject which is so broad that to handle it in its entirety would require a voluminous paper. The writer will, therefore, attempt to concentrate the essential matter of the subject for a general presentation, giving some of the most interesting details of the factors that are important to the industry.

This industry has drawn liberally on the principles of physics and chemistry, and, to a large extent, has had to adapt such information as is most useful—not from data recorded with reference to petroleum, but from data recorded with reference to general treatment of other materials.

Because of the complex character of the petroleum series of hydrocarbons and the fact that data, such as solubilities, vapor pressures, etc., of the different petroleum compounds have not been determined, we are still working by rule of thumb in some essential phases of the industry. Furthermore, the difficulties of determining such data are almost insurmountable. We have not one, but two butanes to deal with—not one, but several, pentanes, hexanes, heptanes, and, as we ascend in the series the complexity and multiplication of isomers increases at such a rate as to make the task of isolating and studying their physical characteristics almost beyond the hope of possible attainment.

The industry is the connecting link knitting the interests of oil producers and refiners into a much closer relationship than ever existed prior to its inception and development. The relation between the producer and the refiner of petroleum prior to 1910 was a rather antagonistic one in a commercial sense. It was to the interest of the producer of crude petroleum to sell it for a maximum consideration; the refiner's interest was to obtain the same product for a minimum consideration; therefore, each side of the business transaction retained within his own hands as far as possible the trade secrets of his business. Each side maintained an attitude of cold-blooded business sympathy only for the other. Cas-

ing-head gas has, in a measure, brought about a different relation, a closer and more frequent friendly intercourse. The consuming public is now beginning to benefit from some measure of coöperation between the two forces vitally responsible for our petroleum supplies. Where formerly the refiner found himself overstocked with a distillation product intermediate physically between gasoline and kerosene, he now finds himself unable to produce a sufficiency of that particular fraction from his refinery operations. The demand for such a product has grown until millions of gallons are required to meet it. The consuming public has been educated through the casing-head demand for this product and its usage of it to accept a wider latitude in the product commercially classified as gasoline, and it would be difficult indeed to estimate at present the increased volume of commercial gasoline that has resulted from the development of the gas gasoline industry.

In the territory referred to as Mid-Continent field, and embracing chiefly Oklahoma and Kansas, the present yearly output of raw casing-head or natural-gas gasoline is something over 100,000,000 gal. Since this product is mixed with from 40 to 80 per cent. its own bulk of refined oil product which would not otherwise be consumed as motor gasoline, the production of casing-head gasoline in this district adds to the available supply of motor gasoline something in excess of 200,000,000 gal. yearly. It is likely that the yield in this territory will now equal that of all other combined fields in the United States and that somewhere in the neighborhood of 400,000,000 gal. yearly of motor gasoline results from the seven years of active development of the industry which has now elapsed.

The industry undoubtedly had its inception along real commercial lines in the neighborhood of Kinzua, Pennsylvania. A little plant was developed there under the direction of John L. Gray, between the years of 1907 and 1910. Other developments which followed this were at Bolivar, N. Y. and Sisterville, W. Va.; but most notable was another plant in the Kinzua neighborhood. In 1910, it was operating continuously and successfully, and in its operation were embodied every detail of development that has been worked out to this date, with the exception of increased pressure. The pressure maintained in that little operation was from 90 to 110 lb. per square inch, gage, using a single-stage, belt-driven compressor. The details of equipment, including automatic liquid traps, were similar to those of modern installations. Refrigeration of the gas under pressure was effected by taking advantage of the latent heat of vaporization of the light cymogene or rhigolene vapors as the liquid condensate was relieved from under operating pressure of the gas. This installation even went so far as to saturate the incoming gas by bubbling it up through the crude oil produced from the lease, and, at the same time, raising the temperature of the crude to a degree that encouraged

the throwing out of a light gasoline fraction from the oil. Attached to the crank shaft of the compressor by means of a small eccentric, was a tiny pump cylinder 7/8 in. bore by 3/4 in. stroke, as I recall it. This little pump forced a naptha stream into the discharge pipe line directly after the connection on the compressor cylinder. The naptha was atomized and probably partially vaporized and carried along with the stream of gas under pressure, combining the functions of operation into a fairly well

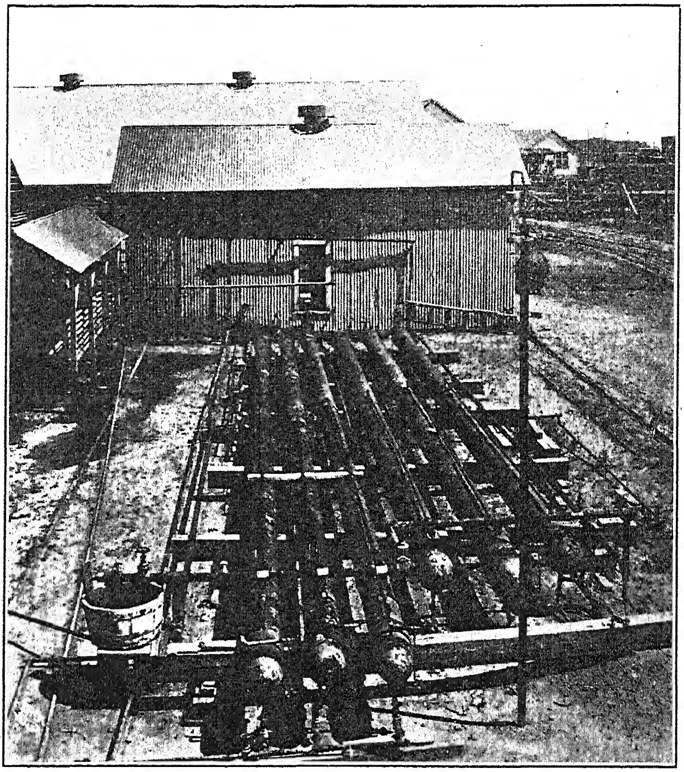

FIG. 1.—DETAIL SECTION OF HORIZONTAL ABSORBERS, IN AN ABSORPTION GASOLINE PLANT. THE ABSORBENT OIL AND GAS UNDER PRESSURE ARE MOVED IN COUNTERFLOW PRINCIPLE WITH SPRAYERS OR ATOMIZERS DELIVERING THE ABSORBENT OIL AGAINST THE CURRENT OF GAS.

worked out absorption plant. The blended product from this plant was as good as that from a most modern equipment operating on the larger scales of the present day. It is only within the last two years that this method of blending has been more or less generally adopted as the best practice in the Oklahoma fields where a high degree of efficiency has been reached. Further history of the industry has but little to add in the way of details of equipment and method of operation. One very important factor which was suggested and applied by the writer, was the increase

of operating pressure from about 7 to 18 atmospheres. This was done in an effort to overcome some of the anticipated difficulties and without a very clear understanding of the physics involved other than a crude perception of the evident fact that the condensible vapor constituents were not present in a very large ratio percentage. Pressures as high as 350 lb. gage have been applied. Results of such pressure application have not been generally considered favorable, so that this extent of pressure application was never adopted except in a few instances.

The average range of pressure application in compression type plants throughout the United States will now be somewhat in excess of 235 lb. gage. The industry had its full recognition of its possibilities in the Eastern fields during the year 1911. In Oklahoma, 1912 saw a more or less indifferent recognition of the possibilities of the industry, following the pioneer development of D. W. Franchot & Co., which may be accredited as the initial development of the industry in the Mid-Continent field. California fields followed with aggressive development closely on the heels of Oklahoma initiative, and, to a large extent, California developed her resources in this industry a year or more ago.

The history of the technical phases of the development is more interesting than that of the industrial. Early and convincing evidence was available that some means not then known would have to be found for determining, roughly at least, the relative gasoline saturation of gases from the different wells and the different fields. A tedious and somewhat expensive course of investigations was made, hundreds of samples of gases being examined. This work was done in the first half of the year 1910, when results of plant operation were available from only a limited number of producing operations. Comparisons were made of samples obtained from operating plants with results indicated by the above-mentioned methods of examination.

Small test compressors were used following the laboratory examination of gas samples. Results by comparison with compressor tests were added, and the present method known as Physical Compression Tests was evolved. Adaptation of the automobile as a means of transporting and operating these little test sets is an Oklahoma innovation.

Two general methods of operation are now applied. We have referred thus far almost exclusively to the method known as compression. A later method which is adapted to handle more effectively gases of light gasoline saturation is known as the absorption method. It had its inception in the lower gas fields of West Virginia, and two claimants having appeared to contend for priority in the conception, litigation has followed.

The first application of this method was made in compressing stations that were used in the transmission of large volumes of natural gas from the producing wells to the point of consumption. The use of an absorb-

ent, extracting entrained heavy hydrocarbons and drying the gas, got rid of liquids which might accumulate at low places on the line or even reach the ultimate consumer in the form of gasoline when temperature conditions were sufficiently low to bring about their condensation. Also, as the value of the gasoline increased, the recovery and separation of even a small amount of it from the very large volumes of gas handled became quite profitable.

This phase of development has extended rapidly within the last two years. Considerable impetus was given through a paper presented by G. A. Burrell during his connection with the Bureau of Mines and at a meeting of the Natural-Gas Men's Association some two years since. It was forcibly presented to this association that nearly every large natural-gas operation could be counted on to produce some small returns of gasoline by the method described. An analysis showed that a recovery of 0.1 gal. or more per 1000 cu. ft. could return desirable profits on the necessary investment. As a consequence, every natural-gas corporation or company began systematic investigation and many developments have gone forward, although some companies have withheld development on account of threatened or anticipated patent litigation.

Within the last year, the absorption method has been exploited for application to gases having a higher percentage of gasoline saturation, but the question yet remains open whether or not this method has advantages over the compression method. Following is a brief description of the two methods involved.

The compression method is applied principally to what is known as casing-head gas, which, in oil parlance, is gas from the casing heads of oil-producing wells. Such gas is more or less saturated with gasoline vapor from the oil with which it has come in contact before issuing from the well. Casing-head gas is usually drawn from the well under more or less vacuum, and this increases the proportion of gasoline vapor in the issuing gases. This removal under vacuum is followed by two stages of compression to produce the 250-lb. final gage pressure of standard plant operation. We have, then, in the compressor operation, three stages of compression, from as low as 1 or 2 lb. absolute to 265 lb. absolute final pressure. The first cooling, usually termed pre-cooling in plant operation, is in an artificially cooled pipe coil between the vacuum pump and the low-stage compressor inlet. Liquid separators are usually interposed at this point as a safety measure to protect the compressors. If the distance between the vacuum pump and compressor intake is considerable, the pipe-line radiation will permit the omission of the pre-cooler.

The separation of gasoline by condensation begins in the first stage of compression following receipt of gas from the vacuum delivery. A separator is provided for the first stage of the precipitation and the gasoline

accumulating at this point is trapped away automatically to storage. The standard intercooler construction of high-pressure compressors is done away with. Coolers, usually of 2-in. return-bend pipe coils, are extended outside and away from the compressor building, and the separator is located at the exit from the cooling coils. The gas is returned to the high-stage compression in a dry condition, and carried through an aftercooler coil and accumulator similar to that of the first stage of compression. Automatic dumping traps are again used here for delivery of the condensed gasoline to storage.

Refinements in the form of refrigeration to reduce temperatures of the gas below those normally obtained are in use in many plants, particularly in the West-coast and Oklahoma fields. The most prominent of these refrigeration methods, as applied to date, are embodied in what is known

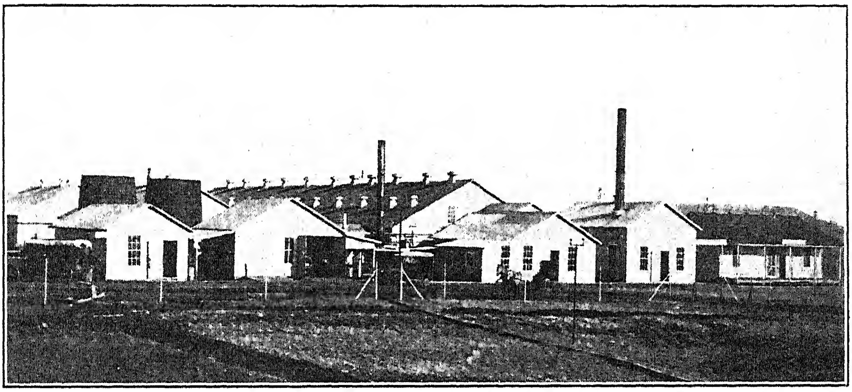

FIG. 2.—CENTRALIZED PLANT FOR PRODUCING CASING-HEAD GASOLINE BY THE COMPRESSION METHOD, NEAR TULSA, OKLAHOMA. PROBABLY THE LARGEST IN THE WORLD.

as closed-expansion refrigeration engines. The gas, after passing the final stage of water cooling, is returned to an expansion engine, a power cylinder of which works against suitable resistance. Interposed on the return passage of the gas to this expanding refrigerating machine is a heat exchanger. The gas expanding through the cylinders of the refrigeration machine is reduced in temperature by the amount of work given out. The cold gas then extracts heat from the in-going gas in the heat exchanger, and temperatures as low as $-60°$ F. are obtainable. This is undoubtedly sufficient to strip the gas of such remaining percentage of gasoline vapor as may be seriously worth recovery. Other compression plants resort to the simple method of passing the residual or tail gas through an absorber at working pressure. A convenient arrangement is a simple type of saturator chamber containing the naptha which is used for blending in the operation. This is just as effective and somewhat simpler in many

cases than the operation of the expander refrigerator machine. Some trouble is encountered in the refrigeration due to the presence of small quantities of entrained water vapor in the gas. The water vapor, however small its percentage, freezes at the reduced temperature maintained and makes trouble. Where naptha is being continually used for blending with the raw output in compression operation, the application of the end absorber is exceedingly simple and involves practically no attention other than continuous pumping of a supply of naptha against the prevailing gas pressure.

A quite recent refrigerating scheme applies ammonia to the cooling of brine and then brings the brine in contact with the residual gas. In California some three years ago, the application of ammonia refrigeration was successfully made and one or more plants of considerable size are now operating in that field along those lines. It is not possible for a compression operation to separate completely the heavy hydrocarbon vapors from the gas in which they are carried, and the increase in gasoline yield effected by intense refrigeration may amount to 10 per cent. or better of the gross gasoline yield of the gas. The condensation of the vapors is less complete when the gas being worked is diluted by any material percentage of air. It is almost impossible to eliminate air entirely from the gas being withdrawn from wells under vacuum. Therefore, from the viewpoint of increased efficiency, the application of intensive refrigeration, or of absorption, for recovery of tail-gas saturation is justifiable in every compressor operation of any considerable magnitude.

Absorption will be described rather with relation to the gas that does not issue from an oil well. We will not consider vacuum as a function of the absorption operation.

It is a well known law of physics, readily demonstrated in practice, that the effectiveness of absorption of gas or vapor by a liquid with which it is present is proportional to the pressure exerted on the gas. It has been found in practice that most effective results can be had in absorption operation under the application of three or more atmospheres of pressure. At pressures considerably lower than three atmospheres, it has been found that the efficiency of absorption operation reduces to an extent involving the calling for excessive absorption equipment by reason of the longer time required. Under this method, where sufficient pressure is not available from the well itself (rock pressure), artificial means are employed.

Absorber chambers are used through which the gas is passed under pressure. The common practice is to inject the absorbent oil through atomizer spray nozzles. The character of the oil usually employed is as follows: a kerosene distillate; color not material; Baumé gravity, 36°–42° (corresponding sp. gr. 0.8448 to 0.8156); initial boiling point, 415° F. (213° C.). The oil, for best results, should have end point of final dis-

tillation not above 700° F. (360° C.), and should have a low viscosity factor.

The gas and oil move in counter-currents. The oil is drawn off continuously and passes through a recovery still where the light absorbed condensate is separated by distillation and re-condensed as gasoline. One and the same stock of absorbent oil is used continuously and requires very little replenishing, in some cases none. It will be seen, therefore, that the absorption method involves the use of a steam plant, as the distillation recovery is conducted with a steam still, and various circulating pumps are required. To date, the apparatus and equipment in use for absorption has not been generally standardized and is in the state of energetic evolution.

A comparison of the relative merits and details of the two systems of operation will be of interest. A clean-cut and exact comparison cannot be made of all the features to be considered, since, as stated, the absorption system is considerably behind the compression system in its present stage of development as against its anticipated possibilities. Enough can be seen, however, to indicate that the two systems operating in competition will be fairly evenly balanced with reference to operating cost, and when all refinements are applied in either case, it is the writer's judgment that the compression system will be found preferable.

Compression System	Absorption System
(*a*) System is now well standardized. Gas-engine power equipment and compressors designed especially for the work are available. The range of operating pressure is also standardized and definite estimates and plans for development are a simple matter.	(*a*) System not so well standardized. In fact, is in process of development and evolution to working standards.
(*b*) Condensing equipment, such as oil separators, condenser coils, accumulators and various details are well standardized.	(*b*) In absorption systems corresponding details are not yet developed to approach acceptable standards. Absorbers of about three distinctive types are exploited. Some details of refinement are to be worked out with reference to absorbent circulation that offer no apparent difficulty of solution.
(*c*) Operation requires skilled attendants familiar with the handling of gas compressors operating to 250-lb. gage pressure.	(*c*) Practically the same limits obtain in absorption as in compression with exception that it appears likely that standards of operating pressure will be very materially lowered by comparison.

Compression System	Absorption System
(*d*) Skilled and experienced attendants are required to handle a very volatile product. Treatment known as "weathering" involved. Use of steam required during cold weather. Storage of unweathered manufactured product requires especially constructed tankage.	(*d*) Steam boilers and stills required to be maintained in continuous operation Product as afforded by methods developed to present date less volatile than in compression system. Storage tankage of a cheaper class is being used. It is most likely, however, that improvements or further refinements in absorption system will bring about condition parallel to compression system in nature and volatility of product. This development will follow because of possible increase, by such development, of sufficiently greater output to justify such refinement.
(*e*) Gas must be treated under artificial pressure.	(*e*) Gas may be treated under natural well pressure.
(*f*) Additional machinery almost invariably used for producing vacuum.	(*f*) It has not yet been determined that vacuum applied to gas wells not producing oil can be profitable.
(*g*) Compressor system admirably adapted to rich casing-head or oil-well gases.	(*g*) Absorption system adapted to dry gas or oil-well gases of lean saturation.
(*h*) Investment for plant equipment, required under most favorable conditions, basis of 500M. cu. ft. unit capacity gas treatment, approximately $30,000. In terms of manufactured product per unit barrel of 50 gal., above figure will reduce to $428.	(*h*) For comparison of most favorable conditions for 500M. cu. ft. unit capacity, $15,000. In terms of manufactured product per unit barrel of 50 gal., above figure will reduce to $1000.
(*i*) Maintenance and upkeep, depreciation, insurance and taxes, classify about as oil refinery operation.	(*i*) Comparable to compression.
(*j*) Over-all extraction recovery efficiency admittedly short of possible recovery by margin amounting to from $\frac{1}{8}$ to $\frac{5}{8}$ gal. per 1000 cu. ft. unless tail-gas refrigeration be used, adding about 20 per cent. to cost.	(*j*) System should attain practically 100 per cent. recovery of extraction product provided steam stills are operated under pressure or small compressors be employed for liquefying light steam-still production. This application has not been generally made to date. It may be assumed that the loss due to escaping light products is greater than the admitted loss or inefficiency of the compressor system. Corrective measures can be applied at a cost within 10 per cent. of total investment.

COMPRESSION SYSTEM	ABSORPTION SYSTEM
(*k*) Value of manufactured product 18 c. per gallon in blended state. Operation of blending at plant adds 15 to 25 per cent. to over-all efficiency as against operation in which blending is carried on separately.	(*k*) Product usually sold unblended. Value for comparison, 20c. Direct comparison of values under this designation cannot be analyzed until more is known from practical results of operation wherein all refinements are embodied.

Costs of operation involving salaries of attendants, lubricants, waste, and plant supplies will be about equal.

In the case of the simple battery of absorption equipment with a recovery still interposed in a pressure gas main, the skill required on the part of the plant operatives may be less than in the case of a compression plant involving all its branches and details when developed to the full extent. It is also likely that a greater degree of skill on the part of attendants will be required for absorption operation in which vacuum and compression are also used, for the reason that the details of operation are somewhat more extended. However, this difference will not be material.

It will be understood in this connection that the absorption system is being exploited in competition with the compression system for the working of rich casing-head or oil-well gases, and when so applied practically all of the refinements and ramifications of the compression system are involved and the only material advantage to be gained is the possibility of operating on gases with a wide variance of saturation with one and the same system without results detrimental to the yield from the rich gases by presence of the lean gases in preponderance.

Many cases arise, particularly in the drilling of new oil properties, where gases of mean low saturation value—say, from ½ to 1¼ gal. per 1000 cu. ft.—must be left out of the operating system because of the reduced partial pressure factor, and the consequent lowering of yield efficiency of the over-all plant output.

Wastes are sustained in this way that can otherwise be avoided. This phase of discussion applies to the development of new oil fields rather than to old developed areas. A problem very difficult of solution is offered in this particular phase of oil operation. The great Cushing pool may be cited as a material illustration. Oil wells in great number came in this field, delivering at the same time hundreds of thousands and even millions of cubic feet of gas of low gasoline saturation daily. This output of gas, of course, was of short duration, as the producing area was drilled in locations sufficiently close together to exhaust the sands of the great gas deposit at a rapid rate. In a period of from three to six months the wells settled down in casing-head gas volume to averages of from 10,000 cu. ft. to 100,000 cu. ft. daily. The only way to obtain the oil is to allow the gas to escape with the flowing oil. The

problem of separation of the gas from the oil is not serious. But the investment involved to provide either compression or absorption equipment for the enormously large volumes of gas thrown off would admittedly be so heavy as to make the recovery of the necessary investment within any reasonable time somewhat questionable. Recently the writer conceived a scheme for separating at the oil well or flow tank into which it delivers its flush oil and gas production, the heavy gasoline hydrocarbons which normally are carried away into the atmosphere with the light gas, and the idea has been submitted to the patent office for approval. In the rough, it will admit a concentration of the heavy gasoline vapors and their separation from the total gas output of the well with rejection and delivery of the lighter gases to any desired channel. If successful application can be made, it will be comparable to the concentration of metallic ores, which has, in many cases, so successfully solved low-grade ore problems.

A few essentials of the technique of gasoline plant operation are well worth noting. The effect of the presence of lean gas in a compression operation and its reduction of the plant yield from rich gases, or gases of high saturation, has been mentioned. This is due to the fact established in practice that an operating pressure of 250 lb. per square inch is not sufficient for adequate removal of gasoline hydrocarbons, but in many cases will allow as much as ½ gal. of product to escape in the residue or tail gas. It is not, therefore, an approved commercial practice to mix gases of saturation below about 1 gal. per 1000 cu. ft. with gases of high saturation, around 3 or 4 gal. per 1000 cu. ft., except in such proportions that the higher saturated gas is in excess.

The dilution of gas with air is equally detrimental; it is a difficult and tedious matter requiring constant attention, where heavy vacuum is applied to the wells, to prevent undesirable amounts of air from being drawn in through leakage. A simple apparatus of the Orsat type is used and the amount of oxygen present in the gas is frequently checked under efficient management.

Very recently automatic oxygen recorders have been worked out and are being applied. Occasionally conditions may be met in which the gas being used is contaminated to a greater or less extent with carbonic acid. Phosphorus cannot be successfully used as an absorbent reagent for oxygen in a gaseous mixture containing a hydrocarbon of the petroleum series. Gas analysis is also used to locate the source of the air leakage. The necessity for taking samples of gas from the pipe lines under a sustained vacuum as high as 27 in. of mercury involves difficulties which can be appreciated only by one who has attempted to secure concordant results under such conditions. Very largely, the work has to be done by men who have not had laboratory experience and who have been hurriedly instructed in the manipulation of the apparatus. Unusual

courage and determination to overcome the vexatious little obstacles of the industry are seen on every hand among the oil operators and investors who have entered this field of the industry.

The paramount feature of commercial interest toward which the casing-head gasoline industry has undoubtedly contributed in a large way is the favorable acceptance by the consumers of motor fuel having an unprecedentedly high distillation end point; in other words, carrying a heavy percentage of a product which in reality approaches the character of kerosene. In the very beginning of the casing-head gas industry it was found practical to use, by mixture or blending with the casing-head product, a large percentage of what was known as painter's naptha. This product alone could not be successfully used in a motor because of the difficulty in getting the motor started, but, long before the day of starting our motors from the seat by electric storage batteries, casing-head gasoline had made their starting by hand possible by giving to the heavy product a light, readily vaporizable fraction.

This starting difficulty was the only obstacle to be overcome in the use of the naptha as a satisfactory motor fuel. Elaboration and extension of this application resulted largely, no doubt, in encouraging, first, the destructive distillation of petroleum or its residues, and, more recently, a concentrated effort to treat the kerosene distillate crude fraction in the same manner.

Efforts are being concentrated by every progressive refiner on the problem of destructive redistillation of kerosene distillates, which amount to a large fraction of the crude. Sufficient success and encouragement has been reached in this direction to insure that within the near future all excess kerosene distillates will be treated in this fashion. It is now evident that from 25 to 50 per cent. of such distillates can be economically converted for use as motor fuel or can be used by blending with casing-head gasoline. This will add to the total gasoline supply an amount equivalent to an increase of 10 per cent. in our total crude-oil production.

Social and Religious Organizations as Factors in the Labor Problem

BY E. E. BACH,* ELLSWORTH, PA.

(New York Meeting, February, 1918)

Statement of the Problem

The administration of industrial organization today embraces more than the cost of production and selling prices. Competition is deeper seated than mechanical devices, overhead charges, and a shrewd manipulation of the markets. Despite the "down-to-the-minute" equipment and the "last word in organization," it is quite evident that "capacity production" will be an unknown quantity until the workman is considered as a producer, in relation to his home, as he is now considered in relation to industry.

Whether or not a man shall do an honest day's work is as much a psychological condition as it is a matter of physical strength or skill. His attitude toward his work each morning is determined, to a large degree, by the environment of his home. Whether this attitude, good or bad, obtains the day through will depend entirely upon the one fact as to whether the corporation which employs him does or does not differentiate between the mechanical factor and the human factor in industry.

To be more specific, sociological work, under whatever name, should be of such a character as to influence the life of a workman in such a manner as to establish a coöperative interest in his work, foster within him a spirit of contentment in his home, lead him so to employ his leisure time that he will not lower his efficiency as a workman, destroy his domestic happiness, or endanger his standing in the community as a citizen.

While no fixed rules of procedure can well be formulated for the development of the work, yet definite lines of activities will readily present themselves as applicable to the individual needs of a community. This is especially true where community influences and agencies pertaining to general welfare are easily correlated.

Any definite work attempted must be determined by the type of the

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community, the character of the population, the predominating industries, the attitude of the officials of those industries toward the work, and the end or purpose in view. Where the population is polyglot in character, a wholesome regard for the customs and institutions held sacred by the non-English-speaking people must be maintained; and this without doing violence to the sacred traditions and principles which are fundamental to this Republic. The manner of approaching the work, and the medium through which it may be done, will vary with the needs of the community and the ideal and vision of those held responsible for its development. It must be non-sectarian, institutional, and of such importance as to command the respect of the community. Whatever the institution, its influence must reach the men, women, and children, and be capable of projecting itself into the home.

The object of the work should not be paternalistic, selfish, nor mercenary, but rather philanthropically patriotic in a broad sense. There should ever be borne in mind a composite of community influences against which a constant check of a correcting character should be made, in order that a healthy, moral tone may be maintained with the idea of strengthening the moral fiber of the nation. Just as numberless tiny strands are woven and interwoven into a cable of great strength, so is a great nation builded from the numberless communities which compose it, and when communities degenerate morally, the nation decays.

Sociological Work of the Ellsworth Collieries Co.

It is the purpose of this paper to throw as much light upon this subject from the practical side as is possible. We all know of experiments here and there over the country, where the human factor in industry has been given consideration, which have proved mutually helpful. In order to be more specific it would seem permissible to cite the work attempted by the Ellsworth Collieries Co. along this line.

To give the matter an exact setting, I will state that the mining towns of Ellsworth and Cokeburg are situated in the heart of the great Pittsburgh coal district. The combined population of the two towns is about 5000 people; the employees number between 2200 and 2500, and the school children number 1200. The company has always maintained a standardized style of architecture; the houses are electrically lighted and comfortable beyond the common conception of housing in mining communities. Labor is organized and work plentiful, the daily production being about 9000 tons of coal and 1000 tons of coke. The Protestants and Catholics each support a pastor, and worship in beautifully designed edifices. No drinking club, licensed saloon, or "speak-easy" can be found in either town.

The population enumerated by families is as follows:

Slovak, 163	Hungarian, 2
Russian, 93	German, 10
American, 79	Bohemian, 8
Italian, 69	Welsh, 6
Polish, 64	Swede, 3
Horwat, 36	Negro, 2
Irish, 23	Serb, 1
Scotch, 15	Austrian, 1
English, 14	Canadian, 1

The problem cited is a typical one in industry at the present time, with a preponderance of the foreign population; each group bringing from its own section and province its habits, customs, and ideals. Crossing the Atlantic has forever eliminated what was formerly the insurmountable barrier of class distinction, and the immigrant has automatically been raised from the servile state of peasantry to the sublime state of a freedman. It must be kept in mind that his ideas of freedom, justice, and liberty are born of his own bitter personal experience, accentuated by hundreds of years of ancestry which has held only a servile relationship to society and government. He is ignorant of the language in which he is to receive his instructions and transact his business. The smattering knowledge which he is to get of its meaning will be empirical. He is separated from his home, and all the tender associations which hold a man to his highest ideals. He is here, in most instances, to "spy out the promised land" of his fond dreams way back in the old country; if it flows with "milk and honey;" he will send for the wife and children.

Lack of social centers and the favorite pastimes of his homeland, drive him to the saloon, drinking club, or "speak-easy," in any one or all of which he can receive plenty of enlightenment upon the question of "personal liberty" and kindred subjects. I know this is not an overdrawn picture, but a mere glimpse of the real conditions which actually exist and must be met. It represents but the foreign side of the problem which, when taken with the native born side of the proposition, forms a complexity of human relationships difficult of solution.

Opportunity for Self-improvement

It may be stated, fundamentally, that it is quite impossible to work out any scheme of helpfulness on the part of the employer unless the employee himself sees the need of it and feels that he is really the projector of the plan. There is no use in starting a machine-made organization with the idea of forcing it upon the men. It is far better to plant the ideas of betterment in the minds of the employees and await development, although this may be a slow process.

Work for Foreign Married Women

One of the most necessary contacts to be made in an industrial community is with the home. The right attitude of the women toward the local industry is a strong asset. After casting about for some little time, it was found that the women in our communities could be interested in sewing. An instructor was secured, and classes for our foreign married women have been successfully conducted in sewing, cutting, and fitting, covering a period of the past 4 years. They receive instruction concerning the selection and use of patterns and modifications necessary to meet the needs of their family. Cutting and fitting, as well as sewing, have been emphasized. The personnel of this class changes largely from time to time for the reason that when a woman has completed her sewing for her family she drops out of the class until it is necessary for her to do more sewing. Women are permitted to enter the classes at any time. The classes are held in the morning and early afternoon for the reason that these are the only hours the foreign women can spare from their daily duties.

In connection with this work, it was also the duty of the teacher of these classes to visit the homes. Her ability to speak the various languages and get in close touch with the conditions placed her in line for helpful suggestions. She made 1103 visits in 1914 and 1094 visits in 1915.

Work for Employed Girls

An opportunity is given employed girls to train themselves in the science of home making. This work has been made as practical in character as is possible. These classes have been composed mostly of the daughters of non-English-speaking parents. It is necessary to impress upon them the American methods of cooking and approved sanitary household practices. The value of foods has been given in a general way, while the working out of well-balanced menus has received special attention. The conservation of food materials has been emphasized through a number of lessons in "leftovers" from meals. Lessons in the packing of dinner pails and luncheons were included in the course. Sanitary conditions in the homes, the "open window" in the bed room, and the inadvisability of "herding" a number of boarders in a home, have all formed a part of the necessary instruction.

Work for Adult Foreigners

Classes for adult foreign workmen have been conducted for the past five years, with the combined purpose of giving them instruction in English in order that they might be able to understand the directions

given them while at work, acquainting them with the fundamental principles of republican government, and, finally, leading to their Americanization through the securing of naturalization papers.

Community Musical Organizations

Possibly one of the best forms of activity and general interest in a community is that which can be united under the head of musical organizations.

The Concert Bands.—An adult band and a boy's band are maintained at both Ellsworth and Cokeburg with good results. The advantage of having a boy's band is that it constitutes the recruiting basis for the adult band. A leader is given light employment with the Collieries company, at a fair salary, and he is paid an additional salary for his office of director of the bands. Two meetings are held each week in each town and interest is thus maintained. The company, for purposes of encouragement, purchases all suits and music. A room is supplied in which to practice; it is lighted and heated without cost to the organization.

It is quite evident that where bands are thus maintained by a company, music will always be available upon special occasions and holidays. Where it has been possible, we have permitted the bands to accept outside engagements, and distribute among the members the fee of engagement, which has at times run as high as $200. It has been impossible to permit the bands to accept all the outside engagements offered them, for the reason that the members are employed throughout the plant in various positions. This type of community activity appeals to all nationalities.

Public concerts have been given in the churches, in the amusement halls, and in the band stand in the athletic park. Fourth of July celebrations, Labor Day celebrations, Memorial Day exercises, and Mine Safety demonstrations have been made especially interesting because of the fine programs rendered by the band. The band, being a community organization, is a source of community pride and promotes a fine community spirit among the employees.

Russian Glee Club.—Great surprises have been sprung in communities by the sudden rise of musical organizations among the non-English-speaking people. The Russian Glee Club was maintained for several years until the outbreak of the present war. This organization did not have any expense connected with it, for the reason that the members of the club practised the selections which they brought with them from the old country, and which they used in the choirs of the Russian church. The only part that the company had in this matter was the securing of a job in the mines for the leader, who was employed elsewhere, and furnishing a meeting place. This organization sang upon several occasions, taking part in some of the public exercises of the town.

Italian Mandolin Club.—This organization consisted of 12 members who had received special training in the use of the violin, mandolin, and guitar. They played at several entertainments in connection with the closing of school, and always rendered a most excellent program.

Croatian Musical Club.—The members of this organization brought their instruments from the old country, and although the instruments were queer in appearance, there was nothing wrong with the quality of the music. There are only six in this organization, but they work faithfully at the home of one of its members.

The Hawaiian Orchestra.—This is an organization of men recently formed, and consisting mainly of the college boys about the town. Mandolins, guitars, and ukeleles compose the instrumentation. They filled several engagements out of town as well as adding interest to many entertainments at home.

The Chorus Club.—This is the most recent organization, and comprises the people in the community who are interested in vocal music, numbering in all about 50. The organization has secured a paid director, who at the present time is busily engaged in training it for a grand concert, which is to be given in the near future, for the benefit of the American Red Cross.

High School Mandolin Club.—This organization is given special attention in the schools and the training is done at regular intervals in a scientific manner. It has a twofold purpose: First, it is valuable as a part of school work; and, second, it will be a reinforcement to community activities after the children leave school.

Athletics

The problem of just how far a corporation should go in assuming leadership in the matter of community athletics has been one of wide speculation. The success of work along these lines depends very largely upon the type of the community. At first, it was thought best for the company to purchase the uniforms and all materials used in the promotion of athletics. The result was that the participants felt no responsibility in any form, and as a consequence the season closed with differences between them and a large deficit to be paid by the company.

A later plan adopted was that of encouraging athletics in every way possible, but having those interested assume all responsibility, even financially. The clubs were required to buy their own uniforms and equipment, and meet all obligations. They were given all money which was earned through athletic activities to apply to their obligations. Social affairs were held to raise money, in which the entire community took a part and the band gave its services. As a consequence the results have been more satisfactory.

Among some of the organizations maintained during the past years have been Senior and Junior baseball teams, two soccer football teams, basketball and football teams, and tennis clubs.

Playgrounds

The playgrounds have been especially fitted for the encouragement of tennis, volley ball, handball, and basketball. A complete modern playground equipment consisting of swings, slides, giant stride, ocean wave, sand boxes, and gymnasium apparatus for the use of the children and grown-ups not interested in organized teams, also feature the work.

The playgrounds are used also in connection with the schools, and the physical instruction is done in a systematic manner, both in school and upon the playground, under the supervision of trained directors.

Organized Clubs

The club has come to stay as a part of the social life of an individual whether he be rich and belongs to the exclusive club in the large city, or whether he be poor and merely belongs to what is familiarly known as a drinking club, in his home town.

It is a well-known fact that in every man's life there are three dominating factors: namely, his home, his occupation, and his leisure time. It is an accepted fact that the manner in which an individual spends his leisure time determines his habits, his efficiency at his work, and his attitude toward his home. He can be more easily approached, he can be more easily influenced, and he will give his most hearty support to that which will afford him the greatest pleasure during leisure moments.

The Official Club.—The efficiency of an organization is determined by the character of the officials who compose it. The realization of this fact leads to the organization and equipment of the Official Club in Ellsworth. Commodious quarters were provided for it on the second floor of the office building. The room was beautifully decorated, generously equipped, and well lighted, through the good offices of the Collieries company. Men holding responsible positions in and about the plant were eligible to membership, and now have an opportunity of spending their evenings in a social way with their companions under conditions which are inspiring and uplifting. The purpose of it all is to provide a meeting place for these men, so that the drinking clubs in the neighborhood will not offer any inducement to them.

The Athletic Club.—This was organized for the purpose of accommodating the workmen and boys of the community who were not eligible to membership in the Official Club. This organization started off with great interest, but it soon became apparent that a club for men and boys was an impossibility. The men withdrew in favor of the boys. Being without a responsible leader, the boys tired of the club, which finally

lead to its closing. The answer to this problem is that the boys should have had an athletic director who could give his time to the various activities in which boys are interested.

Women's Club.—The Women's Club is generally a problem in a community unless it has definite work to do. Usually the only activities of these clubs are get-together meetings for the purpose of discussion of subjects not upon the program. A club thus organized and conducted without purpose is not only undesirable in a mining community, but really hurtful for the reason that it becomes a sort of class affair and the diligent, faithful housewife of a high-class workman, without social aspirations, usually receives no invitation to join the club.

American Red Cross Clubs.—The present crisis has brought into existence two well organized American Red Cross clubs, one in Ellsworth and one in Cokeburg. They have a definite purpose in view, that of carrying through Red Cross activities in first-aid, knitting, and sewing. Two classes in first-aid were conducted, and the members qualified through examinations, and received certificates from the American Red Cross organization at Washington, D. C. These activities of sewing and knitting have reached into the homes of the non-English-speaking people, and it is a great pleasure to see that some of the best knitting has been done by non-English-speaking foreign women. The result has been most satisfactory and the spirit between members has been most encouraging.

Boy Scouts.—Two troops of Boy Scouts have been organized and have carried through the training required by the scout movement. During last summer, one troop cultivated three gardens to defray their own expenses for an encampment covering a period of 2 weeks.

Camp Fire Girls.—Two camp fires have been maintained during the last 3 years and have carried through the plans and requirements of the Camp Fire organization. During the last 2 years they have had their annual encampments covering a period of 2 weeks.

The Pollyanna Girls.—The Pollyanna Girls consists of a club of girls who are not old enough to join the camp fire girls. They have had an interesting lot of activities under the direction of a leader who is one of our kindergartners.

Foreign Societies.—Foreign societies, including the Sokol Gymnast Society, Pennsylvania Slovak Union, National Slovak Union, The Reiter Society of Pennsylvania, Church Societies, Sons of Italy, and Polish Societies are maintained by employees and provide sick, accident, and death benefits.

Distribution of Beer

Everyone who has to do with industrial plants knows the evil effects of an indiscriminate distribution of intoxicating drink among the

employees. While we have neither "speak-easies," drinking clubs, or licensed saloons in either of our towns, yet we have to contend with excess consumption of intoxicating drink, which is obtained either through a club or is delivered in package form to the home. Through a special arrangement with the breweries, this company adopted a regulation for the distribution of beer, covering a period of 2½ years, through its sociological department. The plan was as follows:

A man was employed in each town, whose duty it was to receive orders and money for beer from employees. He transmitted the order in person to the brewery from which the employee ordered it. The plan was that of controlling the quantity sent to each home and minimizing the excess quantities which featured in weddings, christenings, and holidays.

The result was not so satisfactory as had been anticipated, for the reason that it was soon discovered that whiskey was brought into the town surreptitiously, and that if a man did not get as much drink as he wished in the home he had only to go to a nearby drinking club with which he was familiar. The quantities were reduced, however, as the records show. Later, the men themselves decided to establish such departments under the supervision of their local union. This has only started, and no report can be made at this time concerning the movement. We are hoping that results will be satisfactory and for this reason will lend our assistance, whenever desired.

Charity and Delinquency

The charitable and delinquent phases of our work are done through a coöperative arrangement between the welfare department of the company and the authorities of the County Directors of the Poor Board. The Children's Home, Mothers' Pension Bureau, Industrial Schools, and County Juvenile Court.

Health

The instruction in the care of health is given through medical examinations, oral hygiene, frequent biological tests of drinking water, distribution of literature, and personal visitation.

The Ellsworth Collieries maintains its own dairy consisting of a 20-unit plant. Care is taken to produce the best milk possible, under regulations designated by the State Department of Agriculture. The milk is sufficiently high in quality to be certified, and is given to employees of the company at the same price that milk from other dairies is sold. The infant mortality has been reduced 50 per cent. during the past 5 years and much of the credit is due to the use of pure milk.

Religion

Acting upon the belief that a man who belongs to some church is better than one who belongs to no church, it has been the policy of this company to assist all churches in the promulgation of their work among its employees. It has never dictated to its employees in regard to religious privileges nor has it interfered with any religious activities. Both Protestant and Catholic churches are in a very prosperous condition.

Politics

The time of the "company-ridden" employee is past both in work and thought. The best employee is one who thinks for himself upon all matters pertaining to his work, his religion, and his politics. For this reason, this company does not interfere with a man's political opinions. All candidates for office are given an opportunity to address workmen outside of working hours, in order that they may form an unbiased opinion of the relative qualifications of candidates for office. All voters, native or foreign born, are encouraged to exercise their prerogative upon all occasions, because the right of franchise is a sacred trust in the hands of the citizens of this Republic.

Conclusion

This is a comparatively new field of research, as such, although in the last analysis, human nature does not differ much in industry or out of it. The recognition of the human factor in industry, in whatever form, is bound to become more important as labor conditions become more acute. This is especially true where the foreign factor predominates. The field of investigation is large and none are barred. Let us work out the problem faithfully and help one another.

As Edwin Markham puts it:

> "There is a destiny that makes us brothers
> None goes his way alone:
> All that we send into the lives of others,
> Comes back again into our own."

DISCUSSION

Sidney Rolle, Chrome, N. J.—I should like to ask if Mr. Bach does not think it rather harmful to let the men depend entirely on the company, whether it would not be a good plan to let the men aid a little in the support of these organizations? Also whether he has had any experience with utilizing the Y. M. C. A. in this connection.

E. E. Bach, Ellsworth, Pa.—That question is always raised whenever there is discussion upon this subject. So far as we are concerned that would not help a bit; our people do not have that feeling, because our company has a corps of humane officials. I remember when the assistant general manager lived in one of these mining towns. His difficulty lay in that he admitted every one to his office regardless of nationality or position. If the man had a complaint or thought he had one, he had the right of way to his office. That is the spirit that predominates all through it. This is also the spirit of the mine foremen, two of whom were trained in our own night school; it is the spirit of the fire boss and it is the general spirit of the people. They do not feel that we are trying to hand them something. As to the Y. M. C. A., we feel that it would be impracticable for us.

R. H. Vail, New York, N. Y.—It would be very interesting if Mr. Bach would tell a little more about the control of the dispensing of intoxicants. There are many communities where the state intends to do that but does not succeed very well, and as Mr. Bach has spoken of the speakeasies on the environment of these towns, it would be well to know more about the problem of eliminating those.

E. E. Bach, Ellsworth, Pa.—I do not know whether you have had any trouble with beer or not, but we have had. Before I came to Ellsworth, the judge permitted the running of "tap-rooms" where men could go and get a bottle of beer. A man could come out of the plant, go into this place and have one bottle of beer, but could not have any more until he went home and ate his supper and changed clothes. The result was that a lot of people got a bottle of beer, went home and never did come back. On holidays the tap-rooms were closed, and if it was thought necessary to close them part of any day, they were shut. That was before my time, but the money made on this was turned into a certain fund for distribution along various lines of helpfulness. It was not very long before it was discovered that these places were illegal. A little later, the breweries sent their beer into the place. The breweries, by the way, had their foreign agents who would go around and take orders from house to house in spite of anything that could be done, and the result was that our employees could have a bath of beer at all times, if they so desired. We all felt that this was not right, and decided to work out some plan. The judge consented to permit one man in each town to take orders as representing the men themselves; if I wanted a case of beer, I would have to go down to his office and put down my dollar and he would take the dollar and I would sign the order. If I was a foreign man he would have a foreign order, so that I might read just what I was signing. The clerk then transmitted the order and the money to the brewery, if the company approved of my having the quantity. We kept this up for about a year

and kept the records. After about a year the workmen became dissatisfied. As long as foreigners sold them beer on the side, they could easily order from us what we permitted them to have, and if we gave them only one case and they wanted three, they would say "All right, that is enough," and would go and get the rest elsewhere but when we shut off the other source of supply the trouble started.

They also said the bosses came in and saw what they got and so we stopped it for a while. Then they had some trouble in getting beer and asked us to take it up again so we moved the office to the office building where the bosses and everybody else passed. We worked that for about a year, and finally the workmen concluded that they wanted to do the business themselves. They said we were making all kinds of money out of it; I was glad to get out of it, being a minister's son, and so were the rest of us. They organized two departments along the same line and put in their own men. At the present time the beer is coming in; they go down to the breweries and order it themselves, and they are bringing it in in wagon loads; the result is reflected in our accident records. Tuesday is our large day for accidents because they cannot all get out on Monday and the ones that come out are probably just sobering up. As a result we have more people at work on Tuesday and we have more accidents. In Pennsylvania the county judge can grant or refuse a retail license, and can grant or refuse a brewery's license.

Martin Griffin, Rumford, Maine.—When a corporation goes into a new field that is undeveloped, where it not only has to build the manufacturing plant but has to organize the labor, the manufacturer has the whole thing on his hands. Mr. Bach represents one such concern; but in saying that the beer business got out of his reach and had to be dealt with by the community, he indicates that the best work is, on the whole, attained through community endeavors. We have to adapt ourselves to the particular problem, as Mr. Bach has done and as others have done, but we ought to have in mind all the time, the ultimate community object. In speaking of industrial education, I understand and appreciate the necessity for corporations to educate their employees in some degree, but the question is, where shall they stop?

There is an illustration I want to give you this afternoon which has not been mentioned. Some of you know something about it; perhaps some of you are not sufficiently interested in it; that is the Gary school system, at Gary, Ind. The U. S. Steel Corporation had nothing more than a relatively small interest in it. It paid its taxes as others paid theirs, but in Gary, a school system has been built up which takes account of the children all the time and of their parents a good share of the time, and it furnishes the incentive for good work. The attendance on evening

schools exceeds the attendance on the day schools. Here is an instance of building up a school system which takes care of everybody in the community and educates them along the lines of utility in that particular community. One other thing I want to say regarding a corporation's responsibility to its employees. I appreciate that we should do everything we can for them. As all will agree, we must pay more attention to this. To give it to you in just a word, I believe that a corporation should take all the care of its employees that it would take of its best kind of machinery and then add the human element, but I do not believe it can go so far as to exercise control or government. I think a corporation should make the working conditions attractive and safe but it cannot go very much further than this, not in a community which is large enough to have community interests.

C. W. GOODALE, Butte, Mont.—We are facing something of a difficulty in Montana. At the end of this year absolute prohibition goes into effect in Butte. We have probably 15,000 miners at work and a Y. M. C. A. building will probably be completed, or may be completed at the end of the year, but our people are facing quite a problem as to what places our men will have in which to congregate when the saloons are closed. I was talking with a very intelligent labor man the other day in Butte, and suggested the importance of having halls built at different centers in the community where the men could congregate and have a chance for reading and perhaps some games like billiards and bowling and things like that, and I suggested that as possibly taking the place of the saloons. He did not believe that the men would use those places, and as prohibition seems to be spreading, I think that this is something that other communities in other States will have to face. In regard to the housing question, we in Butte have something of a difficulty there. We have a large population, probably 100,000, and a number of companies operating, and the question of sanitation and taking care of the people is really up to the State and County authorities. There has been a good deal of talk about many of these questions affecting dividends. Of course employers are looking to the increase of dividends, but I believ the whole country is waking up to the importance of this care of the workman in a general broad humanitarian sense, and I think we are all beginning to realize the force of a stanza of Kipling's:

Not as a ladder from earth to heaven,
Not as an altar to any creed,
But simple service simply given
To his own kind in the common need.

L. E. REBER,* Washington, D. C.—The Department of Labor, as is generally known, in addition to expanding and intensifying its serv-

* Employment Service, Department of Labor.

ices, has recently added new functions, such as housing problems, conciliations, etc., which greatly increase its responsibilities in the solution of the labor problems arising from the war. This new service affords opportunities for the introduction and establishment of more effective methods applicable not only under the present conditions of emergency, but equally so in the future. For, though the stringency of demand will be very greatly lessened in the period after the war, many of the problems that are now dealt with arise from conditions that are permanent, and measures adopted now for meeting the intensified conditions of the war period should, and to some degree, doubtless will, remain after the war, to the betterment of industry in its normal status.

Chief among the additions to this service are those involved in the reorganization and expansion of the U. S. Employment Service, every branch of which has been signally enlarged. A new function has been added also by which the labor called for in the rapidly increasing war industries is recruited, classified, and, in some departments, distributed. This new work is administered by the U. S. Public Service Reserve, a branch of the Labor Department, which I shall describe after speaking briefly of the present situation as regards shortage and some of the difficulties with which the Department must contend.

Weekly Labor Status reports are received by the Department from all industries related directly or indirectly to the war. From these it is seen that, up to the present time, the reported shortages in war industries have been greatly exaggerated. As a matter of fact, with all that has been seen in the papers about the shortage in ship building, even in that industry it has not been serious up to this time.[1] The chief difficulty has arisen from the lack of means to take care of the employees. This does not mean that there is not going to be a large call for labor for the shipping interests; that industry will require 200,000 at least. There has been and is a labor shortage in industries affecting ship building, such as transportation, but even in these branches if, by readjustments, every available man could be placed where he would be most serviceable, the shortage would be inconsiderable. In the difficulties of the railroads, however, the low relative wages have been a determining factor, and little could be done to improve this situation while the roads remained under private management. Betterment of conditions has been effected through public control; and the comprehensive and thorough readjustment of the industrial wages scale to be made by the Railroad Commission, appointed recently by Secretary McAdoo, will further improve conditions. Though the Labor Status reports show a general, though not alarming, increase in the demand for labor for war industries, an unusually high rate of turnover has been revealed in many of these industries, the

[1] February, 1918.

percentage running as high, in extreme cases, as 60 per cent. per month. This information, coming from the employers themselves, may be regarded as authentic. No industry, of course, can work efficiently with so rapid a turnover.

The three great causes of unrest, as indicated by the turnover, are: lack of housing, unequal wages, and inadequate training. Housing is being provided. Several bills are now before Congress, one for $50,000,000, to be dispensed by the Shipping Board; another for $50,000,000 for other industries, to be dispensed by the Labor Department.

The second need is standardization of wages. If a man can get more elsewhere, he leaves one job and goes to another. A commission appointed some time ago to adjust wages in the ship yards has already standardized the wages scale for the Pacific ship yards, and for some of those in the East. Within a short time this will become general. The Secretary of Labor has appointed a committee consisting of five employers, five union men, and two representatives of the general public, whose duty it is, in part, to find a basis for fixing wages in other industries. The work of these two commissions should speedily lead to better standardization and thus greatly reduce the turnover.

Third is the problem of training. The most menacing shortage faced by the country is the shortage of *skilled* workers. The early calls for men brought out large numbers who undertook jobs for which they were not prepared, and the employers engaged them because they could not get anyone else. It was promptly recognized, however, that many of these employees could be made efficient mechanics in the narrow lines of their previous experience by short courses of intensive training. It became necessary, therefore, to provide teachers without delay for the men employed in the war plants, and it was essential that these teachers be not only skilled in mechanical processes, but also able to impart their knowledge to others. A school was established at Newport News, by the Shipping Board, for the purpose of training employees to teach employees. Arrangements were made with all ship-building plants to send to the school selected men whose qualifications would enable them to gain sufficient training in a brief period of schooling to fit them to impart the needed instructions to the unskilled laborers from whose ranks the plants are so largely filled. It is a serious problem to find men who have had enough foundation to enable them to acquire the teacher's qualifications quickly, but this can and must be done. Other schools similar to that at Newport News have been opened, and all war industries must soon recognize the necessity for this feature. The Government offers every possible encouragement and assistance to this development.

The work of the U. S. Public Service Reserve has been mentioned. This branch of the Employment Service may be more accurately termed an adjustment service. I will describe briefly the machinery which the

Labor Department has built up for this adjustment. It is a voluntary registration. Professional men, skilled workers, and laborers from every part of the country, who are willing to be transferred to the ship yards or to other war emergency work, are asked to register, stating what particular labor they can perform and the experience they have had in that particular occupation or in other occupations, that would prepare them for the thing they express a willingness to do. The Labor Department has appointed a State Director in each State in the Union, called the Director of the Public Service Reserve, who appoints enrolling officers, in every community down to the smallest town in his state. Through this organization the available man power of every State is recorded, and when the Employment Service cannot meet the demands for labor from its lists of the unemployed, the resources of the Reserve are used. Over 250,000 mechanics have already been enrolled to meet the ship builders' needs. A drive to enroll farm workers is being inaugurated, and the boy power of the country is being mobilized by the U. S. Boys' Working Reserve, a division of the Public Service Reserve.

The whole movement has back of it the impulse of patriotism. There is just as much reason why a man should be impressed with the necessity of changing his occupation to win this war as there is for him to take up a gun to win it. It is common experience that the ordinary industrial workers all over the country are willing to change their occupations and go into something else, even at a sacrifice, to help win the war.

Of course, the first thing that every employer thinks is "This is going to take employees from my plant." Now, as a matter of fact, the scheme proposed is that no plant engaged in an essential industry shall have men taken from it, even though they register. In other words, if that plant is doing work essential to the winning of the war, the employees are to be left there, or taken only after consultation with the employer. There is no intention, at least up to this time, to declare any industry unessential. This is where the employer of labor will find an opportunity to show his patriotism. If his is not an essential industry he ought to let his men go, and gladly, because there is only one thing before us now—to win the war.

R. M. Catlin, Franklin, N. J.—I think we all agree that we are in this war to stay, and that we have got to win it, and I think too we all feel that if anything we can sacrifice will bring the victory quicker, down it should go before the altar of sacrifice. But there are a whole lot of things we can do which do not involve a sacrifice and those are the things I want to get at first. I would like to know how far we can go, because you never know until you try, how much you can do. If you have a plethora of labor, a shift boss, for instance, will feel that he cannot go ahead and get a certain job of work done unless he has a dozen men

with him, but if it comes to the point where he has to do it and he has not got that number of men, it is astonishing to find out how much he can do if he has to. Now it is along that line where we can help just now. By and by, if the war continues, it is going to be harder and harder, but if we could only all of us feel that by sacrificing a little here and a little there we can add to the aggregate, it would be very acceptable just now. The trouble is that whatever the employer may do and whatever the shift boss may do, you have still got to meet the objection of the laborer himself. In the days of plentiful labor supply he has been accustomed to think that it takes three or four men to push a car. Because it does take three or four men to push some kinds of car, it does not necessarily follow that it takes three or four to push all kinds of car. Unconsciously people will get into the habit of using unnecessary labor, and then the laborer is himself the man that says, "It takes three men to do this work because you have already established the rate." I think along those lines if we all put our shoulder to the wheel, we can be helpful even though we have to continue as an industry necessary to the war, but we can still help by minimizing the number of men that we require, provided we can get the coöperation of the laborers themselves.

Geo. S. Rice, Washington, D. C.—Has there been any attempt on the part of the U. S. Employment Service to replace men by women in certain industries so as to release the men to go to heavier tasks that require a man's strength?

L. E. Reber.—As to replacing men by women, in some of our circulars we asked the question, "Have you a school where you are training your employees?" and in at least two cases the plant was training women, although it did not have any women employed, which evidently indicated that they were getting ready to use women in the plant somewhere. Until now there has been very little done officially in that direction. Just within the last 4 or 5 days, there has been a committee appointed by Secretary Wilson, consisting of five employers and five labor representatives, to take up all such problems and attempt to solve them. That same committee is to take up wages adjustment so that there will be uniform wages for the same kind of service.

I want to say one thing more about essential industries. I agree absolutely with what has been said. As a matter of fact, I think an industry that is essential today may be unessential tomorrow, and indiscriminately to say, "This is essential and that is not," is hazardous. The only thing we can say is "Here is an industry we have got to have to win the war and we must see that it gets the men, and see also that they are drawn from places to which the least harm will be done;" and that is the reason I emphasize the wisdom of drawing employees from the smaller places. You can get people there and, by a little training, fit them into these jobs and not disturb any important industry.

Lawrence Veiller,* New York, N. Y.—A serious housing problem has been brought about by the increase of certain industries in certain places. Some people may say, "I don't quite see how America needs housing for a hundred thousand people," as some people have estimated; "immigration has stopped, you no longer have that number of people coming here; what is the matter with all the existing houses?" The fact is this; there is the natural increment in population, irrespective of what we get through immigration, and the building industry has almost stopped all over the country, due to a variety of causes that I need not go into here, but will just simply say the war, because it all comes back to that; high prices of labor, high prices of building material, and the inability to borrow money from the banks and other loaning institutions for the construction of working men's houses. The normal housing problem is one thing and the housing problem today in these war times is a totally different thing. You gentlemen are concerned with it at both times. Experience shows that it pays the enlightened employer of labor, whether he is operating a mine or making automobiles or corsets or stockings or shoes or any commodity, to improve in every way he can the living environment of his workers. Employers have recognized that for years past in welfare work, which usually has not got very much beyond giving employees baths, feeding them fairly well, and having a recreation system of some kind. Today every employer of labor is faced with this problem, not only "How shall we attract to our plant the right kind of labor?" but, "How shall we keep it after we get it?" Now the ordinary working man with the freedom to pick and choose that he has today, with the mobility of labor that exists today, is not going to live like an animal any more, he is not going to be contented to sleep in a barracks, 20, 30, 50 or 100 men in a long dormitory of double-deck bunks, with everything human beings ought not to have. That is a relic of the past, and the far-seeing employer of labor, with his eyes looking toward the future, realizes it, and realizes that good housing pays, that he can charge off a certain percentage of his payroll every year and put it into housing even if he does not get a cent back. I know of one large manufacturing town not very far from here, where the manufacturers of that town have come together and said, "We will each subscribe one-third of 1 per cent. of the money we spend on our labor turnover just for housing and do it for 5 years," and I believe that amount of money would finance all the housing that town needs. You gentlemen know what the situation is with regard to the labor turnover today and the cost of it. Those of us who have studied it all know, that the cost of replacing a man is estimated to be anywhere from $10 to $50. It differs in different places. It is possibly a conserva-

* Director, National Housing Association.

tive and fair statement to say that on the average it costs $40 to $50 to replace a man. No one has estimated what it costs in loss of time today when the main manufacturing of the country is in war industries and loss of time is a vitally important thing.

So much for the normal situation; here is the war situation. There is a shortage of houses in most communities where they are having normal operations, then we have in addition all these war towns, places where they are building ships, manufacturing munitions or making parts of liberty motors or airplanes, or something else needed in war industries that they were not making at all before in that place, and they have brought 5000 to 20,000 more people to that town in a few months or a year. Of course, they want houses and it is now therefore apparent that the Federal Government is forced to provide means for getting houses and getting them quickly, if we are going to win the war in the time we want to win it.

Shelby M. Harrison,* New York, N. Y. (written discussion†).—Your secretary requested a brief description of the Russell Sage Foundation, in order that members of the Institute, if they should desire to avail themselves of it, would know what type of service is offered to them through our institution. The foundation was established in 1907 by the gift of Mrs. Russell Sage of $10,000,000 as a capital fund, the income of which is to be spent for the improvement of social and living conditions in the United States. One of the lines of activity which the foundation has felt would lead toward this end is the development and promotion of community surveys; and because the scope and methods followed in these surveys are very similar to the scope and method of much of the institution's work in general, an idea of its main activities can perhaps be given best by describing one of our surveys.

Incidentally, it may be pointed out that antecedent to the survey stand at least two important facts: first, the recognition that communities are active, not static forces, that they develop, that changes in material and human relationships occur continuously, and that with them come new social and civic problems which must, in many cases, be diagnosed and prescribed for anew; and second, the reality of scientific advances along lines which make possible at least some measure of solution of the problems.

Evidences of these changes are abundant; many of them are found in the rapid growth of cities in the last few decades. Villages in agricultural districts, places where everybody knew everybody else, where the pulpit had been long the chief or only influence molding public opinion, where the air was unclouded by the smoke from factory stacks, where the water supply was not affected by pollution, where sunlight and building

* Director, Department of Surveys and Exhibits, Russell Sage Foundation.

† Received Apr. 5, 1918.

space were plenty, these villages in little more than a generation have leaped to the size of cities, with many of the more complicated problems of sanitation, health, housing, recreation, delinquency, city planning, and the like. Moreover, while these changes have been taking place, women in large numbers and multitudes of immigrant peoples have been entering many kinds of industrial life, and the services furnished by the municipality have tended to broaden and increase. These are important changes; but only a few of the many which have introduced maladjustments into community relations calling for new study and constructive effort.

On the other hand, a counter and more hopeful process has been going on, the development of analytical methods for diagnosing these problems and the accumulation of helpful information on corrective and preventive measures. The advances of sociology, of education, government, public finances, have been very marked, but not more so than the big strides which have taken place in the science of public health and sanitation, the fields which touch almost every side of individual and social welfare.

In the midst of this growth of corrective resources, on the one hand, and the changes causing new community problems on the other, the survey has been brought into use. Through it the current problems and the proposed remedies have been brought together. In other words, the survey has meant the application of scientific methods for social betterment.

The most recent general city survey directed by the Russell Sage Foundation was that in Springfield, Ill. It began with a group of Springfield citizens who had been giving some thought to social conditions in their city, had become dissatisfied with them, and had decided that the time had arrived to get out of their maze of conflicting opinions and beliefs and, if possible, onto a basis of certitude in working for community betterment.

There were some citizens, for example, who believed Springfield's public schools the equal of any in the State; others believed they needed to be readjusted to the changed conditions under which the oncoming generation must live and work. Some boasted of the city as the "healthiest place in Illinois;" others believed the number of deaths from preventable causes was too high, and public health appropriations too meager. Some believed that local strikes were due to union agitators who wanted to kick up a fuss; others, that they indicated something wrong with wages, employment opportunities, and general working conditions. There were those who believed law-breakers got what they deserved, but others were of opinion that ill-treatment of offenders provoked crime. And so on, the opinions and beliefs were as conflicting and various as they are in every live, growing American city. Fortunately, the few interested citizens thought it important to give them the test of fact

A survey committee of twenty-four was organized. The chairman was a State senator, and among the other members were a former lieutenant-governor of Illinois, a State commissioner, the city superintendent of schools, other public officials, business men, labor leaders, clergymen, doctors, women's club leaders, editors, teachers, and social workers.

The survey comprised nine main divisions, which, outlined in mere skeleton, were as follows:

A survey of Springfield's schools, including: the school plant, the children, the teaching force, class-room instruction, course of study, financial administration, medical inspection, intermediate schools, vocational education, educational extension, etc.

A study of methods of finding and caring for mental defectives in the schools and in the community; commitment, treatment and discharge of the insane, and care of alcoholics.

A survey of Springfield recreation, including: the homes, schools, parks, streets, library, museum, semi-public institutions, commercial amusements, athletics, festivals, pageants, and public celebrations.

A study of housing tendencies and the legal aspects of housing in Springfield.

A survey of the Springfield charities, including: the children in Springfield institutions, the charitable care of the sick, family disabilities and causes of distress, the social agencies dealing with families, financial considerations, etc.

A survey of work conditions and industrial relations, including: health hazards in industry; hours of labor; child labor; wages and regularity of employment; social effects of work conditions; efforts for industrial betterment, etc.

A survey of the efficiency of the public offices, including assessment and collection of taxes and other revenues; disbursement methods; organization of city administrative functions; budget; city department efficiency; county administrative work; the park board; publicity and reports, etc.

A survey of Springfield's public health, including: infant mortality, contagious diseases of children, the tuberculosis situation, typhoid fever, venereal diseases, city water supply, sewerage and sewage disposal, wells and privies, milk and food supply, and city health department.

A survey of Springfield's correctional system, including: the disposition of cases of arrest, the use of fines, hours to leave town, suspended sentence, jail sentences, indeterminate sentence and parole; probation of adults and children; detention of children; the juvenile court; legislation needs; and the work and policy of the police department.

The facts collected in these nine divisions were in due time analyzed and interpreted, and were followed by the working out by detailed recommendations for improvement. All of the reports were fully summarized

in the local Springfield press, the newspapers handling from 12 to 30 full-column stories on each report. In addition, an exhibition of survey findings was held in the State armory—which was open for 10 days and attracted thousands of visitors, including many from distant parts of the State. Finally, the complete statement of findings is being published in separate illustrated volumes, and a library edition of three cloth-bound volumes is being prepared. These reports are believed to contain suggestions for other American communities.

In addition to the Springfield volumes, the Foundation has from time to time published the results of other studies which may be of interest to this Institute. A full list of publications will be sent to those applying at our office in New York. All I can do here is to indicate a few only by title:

Carrying Out the City Plan, by Shurtleff and Olmsted.
Delinquent Child and the Home, by Breckinridge and Abbott.
Fatigue and Efficiency, by Josephine Goldmark.
Housing Reform, by Lawrence Veiller.
Medical Inspection of Schools, by Gulick and Ayres.
Model Housing Law, by Lawrence Veiller.
Munition Workers, by Amy Hewes and Henriette R. Walter.
Women and the Trades, by Elizabeth B. Butler.
Work-accidents and the Law, by Crystal Eastman.
Homestead: The Households of a Mill Town, by Margaret F. Byington.
The Steel Workers, by John A. Fitch.
The Pittsburgh District, by Devine, Woods, Commons and others.
Wage-earning Pittsburgh, by Kellogg, Commons, Kelley and others.
Social Diagnosis, by Mary E. Richmond.
Social Work in Hospitals, by Ida M. Cannon.
Working Girls in Evening Schools, by Mary Van Kleeck.
Workingmen's Insurance in Europe, by Frankel and Dawson.

Training of Workmen for Positions of Higher Responsibility

BY F. C. STANFORD,* ISHPEMING, MICH.

(New York Meeting, February, 1918)

THE work of an engineer is to direct natural forces so that they bring about the results that he wishes to secure. Heretofore he has concerned himself chiefly with physical forces and inanimate objects, until he has secured a truly marvelous degree of control over them. The great problem of the present age is to secure a like degree of knowledge and control of the human factor. Progress has already been made along this line, but it is only a beginning. Wilhelm Ostwald says that scientific knowledge enables a man to be a true prophet; but it must be remembered that a good many people do not seem to be able to maintain a high average in prophecy. In short, the average of knowledge is not equal to the average needs of the present time, but continually fails to keep pace with it. It has been aptly said that the really essential need of the period is for more brains; if we only had sufficient knowledge and sagacity we could not only solve all difficulties, but prevent them from arising.

This generalization holds good for an industrial organization. The most vital need of the management is for more brains. The logical course for an engineer in charge of an industrial organization is, therefore, to direct whatever forces may be at his command toward the development, training, and guiding of all the brains in his organization. This is easier said than done, for it involves the carrying on toward two objectives, the maximum of productive work, and the development of the individuals who perform it. This is essentially like the rebuilding and enlarging of a plant, keeping it in full operation the while. On the other hand, if the aim is merely for maximum production from an organization, without offering opportunity for development, the final outcome will necessarily be like that of a plant that is driven at full capacity without stopping for repairs or improvements; it eventually becomes so run down that either a complete rebuilding is necessary or else it has to be abandoned.

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* Chief Electrician, The Cleveland-Cliffs Iron Co.

It is imperative to make provision for the development of the individuals who compose an industrial organization, if the best results are to be obtained.

When the industrial organization is small and the directing head is more or less intimately acquainted with each individual workman, this result is accomplished by personal contact as each problem arises. As the organization becomes larger, results are obtained through department heads who have received their inspiration and ideals from the executive head. Unfortunately, as the organization grows still larger and more complex, this personal contact of the trained engineer and the executive with the workman becomes impossible and the communication of their aims and ideals to the men is lost unless some special method of connection is devised.

A recognition of the general facts set forth above led The Cleveland-Cliffs Iron Co., a few years ago, to institute a definite provision for the training of the men in its organization to a higher level of mental capacity and efficiency, and to maintain as far as possible a personal contact with the workmen.

In February, 1912, an opportunity was given to every man employed by the company, who so desired, to take up a course of study which was being prepared for them. A large number availed themselves of this and classes were formed in various subjects appertaining to the mining industry. The men applying were of many nationalities, very unequal in age, education, experience, and ability to master the work undertaken, and it was found impossible to form groups that could work along together in a satisfactory and successful manner.

Two plans for training were finally adopted. The first in the mechanical department, for the purpose of training men to care for the electrical installation which was being developed very rapidly and extensively. The instructors in this were trained engineers connected with this department, who cheerfully gave their own time to this while carrying on their regular work.

The course in practical electricity and elementary mechanics covered a period of approximately 2 years, with class meetings one or two evenings each week during about 8 months of the year. This class period usually lasted about 2½ hr. each evening and, on account of the enthusiasm of the students in the work, it was frequently necessary to send the students home after the lapse of this time. About 40 students were enrolled in the first class, of whom 28 were given diplomas showing completion of the course. A considerable number came into the class so late that they were not able to finish the work, and these were carried into the second class. On account of the serious illness of the instructor in electricity, the second class has not yet completed the prescribed course.

The principal subjects covered in the class work are as follows:

Magnetism
Static electricity
Electricity in motion
Resistance
Ohm's law
D.-c. generators and motors
A.-c. generators and motors
Electric symbols
Circuit prints
National electric code
Low-voltage wiring
Primary wiring
High-tension wiring
Mechanical drawing
Shaft cables and underground wiring
Telephone and signals
Electrical nomenclature
Induction motors
Synchronous motors
Rotary converters
Cable splicing
Meter testing
Testing for faults
Care of electric apparatus
Dielectrics and insulation
Wire tables and computations

Some of the subjects covered by informal lectures are the following:

Electric hoists and hoisting
History and development of mine drainage
Methods of testing electric mine pumps
Electric-driven air compressors
Conducting high-potential current into mines
Installation and care of electric pumps
Power losses in tram systems
Engineering features of electric tramming and haulage
Dielectric stresses and potential surges.

No pressure was brought to bear in securing students other than presenting the idea that the best-trained men will always be the ones to secure the best positions whether with this company or with other companies. The classes were made up of machinists, electricians, helpers, foremen, linemen, and one or two surface foremen. The results of this training have more than met all our expectations. We have not one mine electrician, district foreman, or general foreman who has not taken the class work, and the effectiveness of the training given is clearly shown by the high class of work done and the minimum amount of trouble that occurs. Almost without exception, the men in our electrical force have had no experience outside this company. The instructors have always had in mind practical application of the subject under study to the work actually under way or the trouble that has just been cleared.

One of the most desirable features of this method of training is that it gives us the personal touch with the men and enables us to measure their ability and efficiency. It allows the workman to know the engineer better and to a degree absorb directly a part of his trained experience. It makes the men reliable in an emergency, because they know what to do and how to do it; also, they have measured their executive superior and feel that they can depend upon him for full support and help. Further, the engineer having had the opportunity of personal contact with the higher executive, is able to transmit in a measure the aims and ideals of the management to the workman.

The disadvantages of this method are that it is not always easy to apply in a complex industrial organization, and also that the department engineers are usually crowded for time to carry on the work properly, and it throws a considerable burden upon them which may result in the neglect of more important matters.

The second plan was for training mining men for positions of minor executive capacity such as shiftbosses and foremen. The instructor for this was employed for this specific purpose and while engaged in this work devoted his entire time to preparation and instruction.

When the second method of training was undertaken, it was necessary to select the right group of men to be trained, and it was finally decided to deal with English-speaking men only, who had had some schooling, and who were recommended by their superintendents or mining captains for their ability and mining aptitude. The first class consisted of 38 men, of an average age of 32 years, the youngest being 22 and the oldest 50 years of age. These men had had an average of 4.3 years of schooling, the time spent in school ranging from 2 months to 10 years. The racial composition of the class was as follows: American, 13; English, 12; Finnish, 4; Swedish, 2; Italian, 2.

The choice of subjects to be taught was governed by a number of factors. The men having had so little of the public school system of education, it was undesirable to proceed along those general lines, and it would have been impracticable to have done so in any case, since the men varied so widely in the amount of progress they had made through the public school system that it would have required a series of classes for the different grades. The auspices under which the school was conducted made it essential that the instruction given should be directly useful, and that it should primarily deal with the mining of iron ore. It was thought best to teach one subject at a time, as being less confusing to the men than carrying on a number of subjects simultaneously, and our experience has proved this to be correct. The following courses were taught in the order named.

1. Arithmetic
2. Elementary drawing
3. Geometrical drawing
4. Mechanical drawing
5. Geology
6. Construction and use of mine maps
7. First-aid to the injured
8. Timekeeping
9. Mine sampling
10. Mine methods
11. Business correspondence

All the class work was done on the miners' own time, and they received

no remuneration from the company for the time given to the school work. In order to provide for changing shifts, there were afternoon and evening classes, and the men attended whichever was practicable twice a week, the periods being 1½ hr. each. As most of the men had families, this work naturally interfered a good deal with their home affairs, and it would not have been feasible to plan the course so that it would have been necessary for them to sacrifice this time over a long period of years. The work was therefore planned to cover a period of 1½ years, and when it was found by experience that it would not be possible to cover the ground in the time at first provided, it was considered better to lengthen the class period rather than to extend the time for the course.

In the study of arithmetic, 18 special lesson papers were prepared, the idea being to relate them as far as possible to the mining industry, to the end that the men should acquire the ability to make calculations regarding the wages of miners, sums due on contract mining, mining costs, and cost estimates. The chief end of the instruction in drawing is to be able to understand and work from a blue-print. The work on elementary, geometrical, and mechanical drawing was based on printed instruction papers. The work done by the men was unexpectedly good and the interest they took in it was evidenced by the fact that the majority of them purchased sets of drawing instruments for their own use. The main purpose, that of teaching the men how to read mechanical drawings, was successfully accomplished, and in addition they acquired system and accuracy. At the beginning they made innumerable mistakes in measurement, but before the course was over they had learned to think and work accurately.

The teaching in geology was based, so far as possible, on the geology of the Marquette range. It developed that some of the men already had a fairly good idea of the geology of the range, and not a few of them had collections of minerals in their homes. Beginning with dynamic geology, the class was taken through structural and historical geology to a study of the Marquette range and of iron ores. The construction and use of mine maps was then taken up; this involved the study of the use of the compass, clinometer, protractor, engineer's scale, and templates for track curves. The construction of maps was explained, the use of datum planes, and the relation of the use of the mine maps to the actual extraction of the ore.

First-aid instruction is, of course, essential for men who are to be shiftbosses, and a good knowledge of timekeeping is equally essential. The instruction in mine sampling not only covered taking the samples, but also their preparation for analysis. The course in mining methods dealt with the general principles governing the selection of a mining method,

after which the methods of mining hard and soft iron ores were taken up in detail.

The course concluded with instruction in the art of writing a business letter. Of the 38 men who began, 33 finished the course successfully. Of the other five, four were obliged to withdraw on account of business conditions that made their attendance impossible. This low "mortality" was both surprising and gratifying, since the graduating class in a technical school is ordinarily only about one-fourth the size of the freshman class. Probably this was due in a large measure to the avoidance of the formal atmosphere of an ordinary classroom and the cultivation of a personal friendship between the instructor and students. This is essential in this kind of work.

As the course progressed, the attitude of the men toward the work changed perceptibly. At first the men were, on the average, indifferent, if not openly antagonistic, although a few of them had already attempted to improve themselves by the help of correspondence schools. Some of the others regarded the work with suspicion, as being intended to benefit the company and not themselves. The announcement by the company that, so far as possible, all the men chosen for shiftbosses would be taken from the class, gave them a definite incentive and assisted in overcoming prejudice, since it was evident that they would benefit from it. During all the latter part of the course the spirit of the men was excellent.

It developed as the class progressed that the greatest lack of the men was the power to do original and independent thinking, so the regular course was supplemented by a series of informal discussions that followed the usual class period and were led by the instructor. Some of the various topics discussed were: Safe methods of blasting down timber; Methods of thawing dynamite; Use of delay-action fuses in shaft sinking; Location of holes in blasting various types of ground; Choice of explosives for different character of ore and rock; Proper methods of charging and tamping explosives; Choice of drilling machines for different classes of work; Elementary features of rock-drill construction; Proper methods of setting timber and the variety of timber to use in caps and legs; Advantages of systematic sub-level work over unsystematic sub-level work; Relative merits of timbered and untimbered raises; Proper thickness of a sub-level slice from the standpoint of safety, costs, and recovery; Inspection and lubrication of hoisting ropes; Testing of safety catches on cages; Cost of producing compressed air; Underground sanitation; Ventilation of metal mines; Sampling of ore and its relation to the marketing of ore; Proper degree of discipline of the shiftboss over the miner; Methods of procedure at mine fires; Treatment of a man overcome by powder smoke, and other first-aid problems; Workmen's compensation law; Proper use of the various report blanks which are filled out by underground employees.

It next appeared that the men were very unequal in their ability and

willingness to participate in a discussion, so a series of monthly suggestion papers was devised to reach the men who were backward in discussion. The student prepared an essay, on any subject of his own choosing, once a month, the instructor aiding him and advising him in its preparation. These essays were much better than expected and caused an improvement not only in penmanship and in English, but also in power of analysis and ability to think along independent lines.

With this method, having a trained instructor devoting his entire time to this work, the workman has the advantage of systematic and skilful teaching. When the instructor is of broad mind and magnetic personality, he will become so close to the men that they will seek his help when difficulties arise; also, he will reflect in large measure the spirit of the organization. If he is to secure the best results, it is well that he spend some time each week with the men, while they are engaged in their usual tasks, so that an intimate relation may exist between them. It is probable, in our own organization, that we shall secure best results by using both methods. The decision as to which is best in any mining organization depends upon the size and complexity of that particular organization in which the training is to be given.

The experience with our first classes, and also subsequently, demonstrates that the ability of men to absorb useful information is dependent upon three things: skill in teaching, practical value of this instruction in their daily work, and probable financial betterment to the workman because of this training. The skill and knowledge of our men, acquired in and about the mines, made them better able to understand the instruction where the information conveyed had a direct application to their work, than the average college student, but in taking in abstract information they show a much greater lack of capacity. The work we have done in training workmen for positions of higher responsibility is very gratifying, we believe, both for the men and for the company, and has resulted in a closer sympathy between employer and employee as well as greater efficiency and reliability on the part of the men. Also it goes far toward making us independent of outside help, because we have within our own organization the trained brains necessary for high efficiency.

DISCUSSION

E. E. Bach, Ellsworth, Pa.—The fundamental basis of all effort directed toward improving the human factor in industry, under whatever name, must be based upon the process of education. The type of community, the character of the population, the dominating industry and the administration of educational affairs will largely determine what may be deemed pertinent along educational lines.

For the purpose of our discussion, industrial communities may be

divided into two classes: First, those in which the land, the houses, the public buildings, etc., are owned by the operating industries. Second, those which have been absorbed in the course of the development of an industrial plant, in which nearly everyone owns his own home.

The type of educational work may vary greatly in such communities because of the local conditions. In the first class, it is usually quite easy for an operating industry to have the schools take on any phase of development which it desires, through augmenting the school tax by cash contributions. It has not been very long since schools in this type of community were neglected and fell far below the efficiency of surrounding districts.

In schools of the second type, the officials of an industry may be progressive and desirous of seeing the children of their employees given better advantages, but they are powerless because they have no representation upon the school board. It is often difficult to secure a voice in the school affairs of these old-time communities despite the assurance of well-meaning companies. Members of the school board usually persist in declaring that the "new-fangled" ideas are only a scheme to further the interests of the company and place the costs upon the backs of the "faithful" tax payers, who usually judge the efficiency of the school by their ability to hold down the millage.

I am a firm believer in the old maxim, "Whatever you would have appear in the life of a nation you must first put into your schools." It naturally follows that whatever you would have appear in the life of an industrial community must first be put into the schools. By school work, in this instance, we have in mind any educational work done during a day session or during a night session; in the school or in the home. School work, as I take it, must be sufficiently comprehensive to include a program of self improvement for the men and for the women as well as for the children of a community. While I do not discredit the old Hebrew philosopher who said, "The breath of school children has saved the world," yet I am persuaded that, aside from providing adequate facilities for the education of children, the school system in an industrial community must provide for the advancement on the part of the father whose education may have been neglected in his youth, as well as offer an opportunity to the mother in the home for supplementing her training in the greatest of all arts, that of home making. Fundamentally, then, that school system is best adapted to the needs of the community, which projects itself farthest into the home and touches the life of the individual members of that home in a helpful manner.

The leading educators of the present time have no disposition to discredit academic training for those who need it, but they also realize that where this is not possible, provision must be made along other lines if such practical ends of education are to be sought as: the training of

children toward work rather than away from it; the making of education serve as a door through which they may enter life rather than as a window, through which they may see life; or the harmonious development of all of the powers of the children to fit them for complete living.

The Public School

Playgrounds.—In considering the regular school work for children, I hold it doubly essential that they should have regular access to a playground or gymnasium. The basis of all education is the self-activity of the child and I know of no better place to foster it than in a supervised playground under trained directors, who understand children. Play is an essential part of the life of every child; it is not a luxury but a necessity. It is not something which a child might like to have but it is something which a child must have. If this is true, then how important it is that a child shall play under the best possible conditions; under the supervision of directors whose lives are clean; under those of adult experience who have not forgotten the sources of their happiness during their own childhood.

Among the apparent results gained from a supervised playground are the following:

1. The destructive spirit which children usually have is turned into healthy rivalry through competition in games.

2. The spirit of filching property, so common about public works is eliminated, by strengthening within the minds of the children the sense of responsibility.

3. The virtue of justice is strengthened by not permitting any child to dominate a favorite game.

4. The proper social relationship is established through the arbitration of differences which arise from time to time.

5. The leisure time of a child is occupied with happy and useful employment and thus diverted from mischief.

6. The busy housewife is relieved of the care of the children for a period of time each day, without the element of worry constantly harassing her.

7. Where home conditions are bad, the playground relieves the situation and serves a most helpful purpose.

8. The supervised playground always becomes a community center where both children and parents can meet and spend the evening in a most delightful way.

For these reasons I believe that the supervised playground should be a part of the educational scheme of every industrial community.

Kindergartens.—The work among the smaller children of the playground can be easily conserved through established kindergartens.

By thus supplementing the free play by the purposeful play of the kindergarten, which is based upon psychological development, a most important step is gained in a child's educational development.

The kindergarten is of especial value in an industrial community where a large proportion of the children are of foreign extraction. The kindergartner has discovered the great secret of educating the foreign child, that before a foreign child can be taught to read or write English it must be taught to understand and speak English.

Among the advantages of a kindergarten are the following:

1. A foreign child, who is permitted to spend 2 years in the kindergarten before the age of six, can take up the regular school work with nearly as much facility as a native-born child.

2. Kindergarten children always advance more rapidly in the grades than other children, because they have acquired a foundation for all subsequent work. In our schools, the reduction in age in 5 years has varied from 1¼ to 2 years, where children have had kindergarten training.

3. The housewife is relieved of the care of the children for a half day, and the child gains wholesome experiences, which it would be impossible for it to gain in any other way.

4. The work of the kindergarten can be made to articulate with the subsequent school work, thus ushering the child into school in a most natural manner.

5. The mothers' meetings which are held monthly to which the mothers of the children in attendance at kindergarten are invited are a most helpful source of contact with the home.

Vocational Training.—The modification of the course of study in such a manner as to provide instruction in subjects which are of vital importance to the life of industrial communities and eliminating subjects of lesser importance, is one of the steps in advancement in the education in industrial communities. Safety, first aid to the injured, and home nursing are vital subjects in industry and could be taught in connection with physiology and hygiene. This is especially important in industrial communities where there are a large proportion of non-English speaking employees, because there is no better medium through which to instruct an adult foreigner than through his child, in his own language. The science of home making, including the household arts of cooking, sewing, laundering, baking, and scientific study of food values, should all be a part of the school work in an industrial community, because it is now an accepted fact that wholesome and well-prepared food is the most effectual safeguard against the drink habit.

Workshops for boys should be provided in connection with the schools in order that their hands may be trained to work with their minds and thus increase the skill of both.

The regular academic course in the public schools should be followed only as far as the sixth grade. The seventh, eighth, and ninth grades should diverge sharply toward pre-vocational training for those who are not interested in preparation for college. The work of the tenth, eleventh, and twelfth years in the public schools should be largely vocational and the students should be given an opportunity to spend one-half of their time in the shops of their chosen vocations, thus working out an apprenticeship for which they should be paid and given full credit at graduation.

Night Schools

Let us now consider what the schools in industrial communities shall provide for the adult. The most feasible proposition seems to be that of conducting a night school. The work must be so formulated as to lead to the immediate advancement in the every-day work of the employee. The most essential feature of these classes is an intelligently prepared course of study which shall specifically outline the material which is to be brought before the class. It should give the student the power to grasp the fundamentals and thus enable him to reason out for himself problems which arise from day to day.

Every industrial community should provide instruction in English for the non-English speaking employees. There can be no greater step forward in industrial efficiency than the training of this type of workman for his place in the great scheme of industry, to say nothing of the Americanization part of the problem.

Opportunity should be given, for self-improvement, to the girls who are forced to leave school in order to help in the home or to earn a livelihood. For them the course in home making seems to be the most practical one.

Boys who are forced to leave school in order to help their fathers to carry the burdens of the home and provide for the younger children, should be given instruction in the night schools along the line of their chosen work. Special emphasis should be given to applied mathematics, practical English, elementary drawing, etc.

No system of education in a community can lay claim to filling its mission adequately which does not provide an opportunity for the wife to improve her condition through instruction which shall facilitate her work in the home, add to the health and comfort of her family, and help her to clothe herself and children economically.

Corporation Schools

Perhaps the best example of correlation between industry and education is what is known as the Corporation School, which was organized

for the purpose of giving special training to employees of large industries. The object as stated by the organization is as follows:

"To bring into one cohesive organization all of the large industrial institutions of the United States and through this organization prosecute vigorous activities to the end that the problems of waste, through unnecessary labor-turnover, waste through lack of proper training, waste through unnecessary sickness and accidents, may be minimized and, where possible, eradicated."

I feel certain that the officials of large corporations should be made to feel keenly their duty toward the human factor in industry. The workman should be afforded an opportunity to make up his deficiencies of undirected or misdirected youth through having access to some form of education which will fortify him in his chosen work. Industry has no greater asset than an intelligent workman.

F. C. Henderschott,* New York, N. Y.—I am going to take, as the text of what I shall discuss, a portion of the second paragraph of Mr. Stanford's paper. It read as follows: "The most vital need of the management is for more brains. The logical course for an engineer in charge of an industrial organization is, therefore, to direct whatever forces may be at his command toward the development, training, and guiding of all, the brains in his organization. This is easier said than done, for it involves the carrying on toward two objectives, the maximum of productive work and the development of the individuals who perform it;" and the last sentence of the paper; "Industry has no greater asset than an intelligent workman." The United States of America, at the outbreak of the present war, had the best equipment of any nation in the world. That statement holds not only for our shops and our transportation systems and our stores and our farms and our homes, but it holds generally. There was no other nation in the world that had so good equipment as the United States. There was no other nation in the world that could be called progressive that has such poorly trained workers as the United States. Even Norway, Denmark, Sweden and New Zealand ranked ahead of us. Now that is the problem, generally speaking, and there was recognition of that fact, a growing recognition which took form, and one of its forms was what we call the corporation school. Now obviously a corporation has no particular educational functions, but as is said in the closing sentence of Mr. Stanford's paper, or as is implied, an industrial institution is, after all, the reflection of the aggregate of the efficiency of the individuals who compose that organization. There is no way of getting away from that. If your individuals, from your president down, are efficient, if your individual has developed his brains, if he is a trained man, you have got an efficient organization, and if you

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haven't that condition, you have got weaknesses and your organization is no stronger than those weaknesses. I maintain that the same thing holds for a nation; a nation is as efficient as the collective efficiency of the individuals who compose the nation, and no more so.

The National Association of Corporation Schools was started five years ago and it has been my privilege to be the executive secretary of it since its birth; in fact, I think it is my child. It now has 110 of the large corporations in this country doing some educational work, but recently the developments have been very rapid. The latest development is one made by the War Department, of organizing all of the educational forces of this country under one committee, consisting of three officers of the War Department and five civilians. One of the civilians is the president of our organization, Mr. Dietz, who is educational director of the Western Electric Co. Dr. Mann of the Carnegie Institute is another. I cannot give you all the names, but they are big men. The object of that Committee is to mobilize all the educational forces of the country, first, for war needs, and military necessities, and second, for after-war conditions; because, after all, were it possible to stop right short at this time and make a survey of what is going on in the minds of engineers and other trained, intelligent people in this country, you would find that 90 per cent. of them, or somewhere near that, are wondering what is going to happen when peace is declared, are wondering what are going to be the conditions. Are we going back to the world that we had when this war broke out, or are we going to have a different world? What is labor going to do? What is labor going to do in England, in France, in this country? To my mind there is no question that labor is going to play a more prominent part in management than it has ever played before in the history of the world. You have got to trust labor; you have got to educate labor. But there is one thing we do know; the United States has the wealth; I do not believe there is anyone here who will deny that we have the brains; we have the vision; we have the ability; we have the health; and we have the raw material.

Production is not the big problem; you solved that 30 to 40 years ago. When that span fell on the St. Lawrence River bridge not only engineers were astonished. You are accustomed to digging a tunnel under the East River and having it come together not over half an inch apart. Engineering is a science, but marketing is not. Equipment has been reduced to a point where we are proud before the whole world, but what about the people who handle the equipment? Mr. Vanderlip estimates that there are a billion dollars a year lost in labor struggles. Mr. Claxton estimates that there are two billion dollars a year lost through poorly trained workmen, and that there are probably between two and five billion dollars lost every year through unnecessary labor turnover. There are about forty million workers of all

kinds in this country, and your turnover is fifty million, 125 per cent., for all the industries of the country. In one industry it is 827 per cent., and 75 per cent. of it is unnecessary and neither the worker nor the employer profits by it. You can realize that this is a burning problem, it is the biggest problem in this country today, to stop this unnecessary wasteful labor turnover. There is a distinction in my mind between education and training. Education, as I see it, should be conducted entirely by the public schools and the higher institutions of learning, it is a cultural process, it develops the natural capacities of the individual. Training is for skill; it is what you engineers get after you have gotten your college course. It makes a man skilful, it makes him a specialist in something, it trains him to do some one thing well, preferably the thing he likes to do. That part of it, so far as the workers generally are concerned, must be handled by the industries. Now there is another movement originated under Dr. Claxton which will have, on the Committee that is going to handle it, a representative of the Chamber of Commerce of the United States, a representative of organized labor, and a representative of the National Association of Corporation Schools. The object of this movement, if it is carried out, is to survey every community, preferably under the auspices of a civic organization like the Board of Trade, find out what are the training requirements of the industries of that community and how you are going to meet them. A good example is the situation in Cleveland at the present time. Cleveland is doing wonderful things along that line, but if that is carried out throughout the United States and if this training movement that has been inaugurated by the War Department is carried out, great things must follow. We had a representative of our organization, a specialist, at each of the sixteen cantonment camps, and do you know that after they had been there awhile they worked out a system for all the camps, a card index system, and when a young fellow under the draft was brought in, they asked him about two questions, "How much education did you have?" and "What have you been doing since?" and they could tell him almost to a dollar what wages he was making when he was drafted. It is really quite remarkable when you reduce that thing, but we have never reduced it. I don't know of a single company that takes any accounting of the cost of its labor turnover, yet it is estimated that it amounts to between two and five billion dollars a year. That is the weakness that underlies our present industrial system. We have got to get at it. The Corporation School is one branch of the movement; paying more attention in your community to your schools is another branch of it; keeping the child in school, showing him the money value of education, is another.

Sidney Rolle, Chrome, N. J.—The U. S. Metals Refining Co. finds that there are a large number of foreign workers who distinctly pride themselves on not knowing English and not wanting to learn it. We tried

to get them to go to night school and they said "To —— with the English; I am going back as soon as the war is over." I might add that the largest percentage of our men are from the Central Powers, especially parts of Hungary, and they have shown a distinct antagonism to learning English. I do not know whether anybody has had a similar experience, but we find that one of our greatest handicaps. We also find that it is utterly impossible to put up separate signs in English only; we usually translate them into Hungarian, Slavish, and Polish. Then we have the further difficulty that they all talk different dialects, and when we have a translation made, say, in Polish, another man that comes from a place 10 miles from that man's town says that that is not Polish, and that he does not understand the dialect.

John B. Hastings, Los Angeles, Cal.—Mr. Stanford's paper has not yet reached me, but the title covers a situation I have been thinking of for some time. It has seemed to me the larger mining companies might offer their employees a night school education of the broadest kind. On the theoretical side it should include lectures and classes in all that pertained to mining, milling, and smelting: geology, mineralogy, petrography, chemistry, etc. On the practical side we might use suitable shops for trade schools, teaching machine tool work, blacksmithing, and carpentry. There is no need to enlarge on the subject in this discussion, it may start reflection on the part of others for and against it, suggesting the ways and difficulties of accomplishing results. It would be a source of trouble and expense to the companies that would be repaid by better and more interested workmen. The introduction of lecturers and exponents of both technical and practical ends might be a means of teaching even the higher employees, and I am quite sure the foremen and heads of departments would instinctively be put on the *qui vive* by having inquisitive students of all ages watching their systems. The object would be the general development of the intelligence and skill of the workmen, to the highest possible degree, for the benefit of himself, his employer, and the country. If reading habits could be established they would help as a substitute for saloons, and generally tend to steady the men. Even though it inculcates longing for a better job, that has always been held to be a good thing and is regulated by the "survival of the fittest."

Getting the Foreign Workman's Viewpoint

BY PRINCE LAZAROVICH-HREBELIANOVICH, NEW YORK, N. Y.

(New York Meeting, February, 1918)

I WAS asked by the chairman of one of the Sessions on Employment Problems to talk about the viewpoint of the foreign workingman. I am not a workingman. I have never done what a work-hand might call an honest day's labor; that is, I have never been in a factory or manufacturing plant or in a mine, though in truth, hard work and I are well acquainted. I was a soldier, am an engineer, have long been actively interested in the most important waterway construction in the near East, have served politics and diplomacy, written books and lectured at universities. My knowledge of the foreign workingman in this country comes from the fact that my own compatriots here at various times came to me and appealed for advice and help, and last year I was asked by the employment manager of a corporation to undertake a welfare job at one of their plants. I went out, saw the plant, talked with the superintendent and outlined certain of my ideas which he personally heartily approved, but which did not find favor with those higher up.

I approach the subject of the foreign workman's point of view with the understanding that the industrial employer's effort is for the maximum of efficiency. I am conversant with labor conditions abroad both in industry and agriculture. What I have learned of industrial conditions in America as they affect the foreign immigrant has been chiefly gathered from the cases referred to of foreign workmen who from time to time have come to me with their troubles. In the course of those investigations, in order to give whatever help or advice was possible, I have been impressed with the fact that the great United States industries evidently had not yet sufficiently recognized the value of studying the conditions of the workingman in the lands of his origin across the seas. A careful study of that which could be called the moral element in connection with its foreign labor would give industry a knowledge of the man's reason for coming, what grievances he brings with him, his hopes for a future, and the peculiar character of his capacities. The employer would thereby be enabled to meet the man, to be helpful to him, to aid him and at the same time promote industrial efficiency, inasmuch as a workman who believes that he is being dealt with humanly and squarely is contented and satisfied and will give willingly, and even with pride, the best that is in him; justice and a fair deal is all the man wants.

The conditions of the foreign workman in his home land, and some others peculiar to his situation in this country from the moment of his landing, complicate the foreign-labor problem exceedingly and unnecessarily, contributing many factors of discontent among the laboring classes —factors not created by the indsutry itself, but from which industry becomes the chief sufferer. As an illustration of the recognized paramount value to a great organization, of thorough and exact knowledge of all moral elements in addition to the direct physical ones, consider for a moment the study and mastery which our common enemy, the German military machine, applies to a wide range of conditions in its own home and in enemy lands and in all foreign lands affecting, or that might affect, German policy. The military usefulness of this vast knowledge might not at first sight be appreciated by persons unfamiliar with the vital service it renders in warfare. When the German General Staff studies the efficiency of an enemy army, or even the efficiency of its own forces, the so-called moral element plays an important part in that consideration. This moral element indicates what can be expected from troops, which are the particular fitnesses of a certain body of troops to perform certain particular tasks, and forms the basis of many infinitely valuable calculations. This so-called moral element, which has nothing to do with the training, the drilling of the army, etc., includes the national characteristics of the local recruitment origin of the troops, origin of the officers and of the men, social conditions, living conditions, religious conditions, political views, weakness in the social and economic fabric amenable to destructive agencies, morality in public and private life as reflected in the daily press, the light literature, the records of the courts of justice, statistics of mortgage, charities, etc. The short appreciation of the French army which General Boguslavski, of the German army, made in introducing his study of tactics in the Franco-German war (1870–71) is an instance of the extent to which that moral element is examined with the aim of making the German war machine efficient and irresistible.

So, the efficiency of industrial enterprises taken as enterprises alone, and of the industry of a country as a whole, in considering the labor problem, cannot afford to neglect the study of the moral element, which ought to include the thorough investigation of the conditions and environment of the foreign immigrant workman in his home lands. Incidentally, it may be said that in addition to the value of that knowledge to the mutual relations between the employer and the employed, other rich byproducts of commercial achievement would certainly accrue therefrom to the industry.

The foreign workmen in the United States may be divided into two groups: I, of Northwest European origin; II, of East and South European origin. The first group consists of: British, Scottish, mainly Irish—then Germans, French and Scandinavians. The second group consists of:

Lithuanians, Poles, Russians, Slavs from Austria Hungary, from the Balkans (Macedonia), and of Italians and Greeks. These two groups are radically different in many respects. The men of group I previous to their immigration were, on the whole, industrial workers, or agricultural workers who lived from hand to mouth They come to the United States with the clear intention to settle here, to make homes and improve their economic conditions. The men from group II are generally from agricultural districts, in most cases farmers, many of them owners of some land and a few head of cattle. These men come to this country single, without their families, lured by advertisements which depict the opportunities for earning in America in most vivid and unreal colors. Perhaps you are familiar with the advertisements which steamship agents and labor agents have distributed freely in central, eastern, and southeastern Europe. It is a shameful page. The men have been told stories of gold simply to be found on the streets. The man comes over to earn money to pay off mortgages on his farm, or on that of a brother or of a father. Bad agricultural conditions, bad harvests coupled with political and religious persecution, are the direct causes of emigration.

The Italians and Greeks are in a class separate by themselves. The Italian immigration comes from southern Italy, the land of the *latifundia*, and malaria, and they come less from agricultural districts, where they were only laborers, than from towns. The Greek from Greece is also generally a townsman, who believes in coming here to better his earnings. Thus, the man of group II generally comes with no intention to settle, and he sends all his earnings back to his home.

Characteristics of the first group: Individualistic; brutal and rough among themselves; no coördination; each man for himself; rule of the fist; accepts bullying and rough treatment. Nearly all are married men, having sooner or later their families with them. Their standard of living here is higher than that of the men of the second group.

Characteristics of the second group: Fundamentally coöperative, accustomed to live in economic coöperative groups in some form. Most have been soldiers, hence used to obedience, discipline, hard life, but unwilling to accept brutal and rough treatment. Is generally illiterate, and unskilled; quiet, cheerful, and willing worker. His attitude toward America is not that of a home-seeker but of one who wishes to earn money and is always looking forward to returning home. All his earnings are sent home or hoarded against his return. He retains only what is absolutely necessary for keeping him alive and fit. Hence his living standards are rather low in this country.

The living standards of group I are lower in their home lands than those of group II. Here the contrary takes place: the living standards of group I are far above those of group II, which in America are miserable. Group I spend their earnings toward founding new and better homes in

America. Group II are here in America to earn a certain amount of money and then go back—hence they are willing to do harder work under worse conditions than those of group I. These circumstances lead to the first misunderstandings of those men by the employer. The employer assumes that the men of group II do not know better conditions, and treats them accordingly. The employer cannot imagine that in reality the home standards of living of those men are fully equal to the standards of American workingmen. Further, the employer is astounded that those men will return home at the least call of emergency from their home land. The man coming here does not find the things as they have been depicted to him by the steamship agent and the labor agent; he does not find a land of milk and honey, and he is disillusioned. The treatment he is generally accorded from the moment he lands makes him distrustful and his experience involving questions of good will and fair play and justice are often most bitter.

The man of the first group, individualistic in his tendencies, comes from a part of Europe where the individualistic civilization resembles your own; coming to seek a new home, he quickly finds his place and it is natural for you not to draw any line between him and your own native-born workman. But the matter is different in regard to the Slav belonging to the second group. Coöperation, not individualism, is the basis of all his social organizations. He lives in groups, works in groups, thinks in groups, whether in agriculture, handicraft, or industry. As a crude picture of his way of doing things: In Russia, a dozen men, coming from different directions, meet at cross roads, men who belong all to the same trade—say the carpenter trade—they do not know one another, they come from far separate villages, but coming together at the crossway, they make acquaintance, find they belong all to the same craft; they form a union, "artel," as you know it is called in Russia, and elect a head, the "artelshik." When they come to the next town, the "artelshik" will seek work for the whole union. If only three are needed and the others cannot be employed in that place, three will take the jobs and the money earned by them will go toward the upkeep of the whole group. I take this as one of the most radical examples of the idea.

In my country—I am a Serb—(I know Serbia is a country which is not much spoken of here in America, and more or less put aside. Though we have suffered from the Austrians, Germans, and Bulgars, and are suffering unspeakably more than Belgium ever suffered, it has been forgotten! Do not think I have lost faith in the good heart of America. I know full well what enemy forces at work in this country cause this obscurity. America will come to recognize those forces sooner or later). Well, in my country, before the war, I am proud to say we had no paupers. You can see in the Statesman's Year Book stated under the name of Serbia, "no pauperism, no charity institutions necessary, every man a

freeholder." The man himself perhaps, the individual, does not own more than four or five acres, but it is worked in coöperation. Where in Russia you have the "Mir," that is the village community, as the coöperative unit, in my country we have the family or the working group as the coöperative unit; and you find coöperative units composed of 30 to 40 members, on 100 acres, who live very well, have meat the whole year around, are well clothed, and put several hundred dollars, perhaps a thousand dollars, aside every year as a reserve fund, besides paying taxes and providing for improvements for the next year. Even where the coöperative group meets with poorer success and bad luck, it still produces a free man used to home comforts and some idea of personal ambition. This is at the root of one of the difficulties which the foreign workman of that type meets in this country. You look at him as an inferior being; abroad, in his home, his living standards are as good as those to which you are accustomed. He lives perhaps better in his own country than does the working man who belongs to the first group, and comes from Ireland, for instance. He comes here with the idea of earning money to improve conditions at home. You approach the man; you want to help him, but you think the miserable conditions in which you see him living here are those suited to him. If he ever had an idea of settling here, that idea is often taken away from him during his first few days in the country. If you knew what the workingman from our countries, from what I call the second group, has often to pass through from the moment he lands here, and with what faith he comes to these shores, you would realize his disappointment and the misery of his situation.

I was called upon last year to help a couple of immigrant girls at Ellis Island. I wont take your time telling the story. But one of the girls was switched away by an agent, under my nose, although my wife, who is an American by birth, was there especially to look after the girls. Finally the matter was righted. At Ellis Island the man does not find representatives holding out friendly arms to welcome a new son of freedom, but instead many bewildering conditions, among which are agents of several kinds lying in wait for him. He probably passes through one of the boarding houses called "Immigrant Homes." In some of these he fares well. But there are others, unfortunately; "Homes" perhaps in which the "rich Mrs. So-and-So and the rich Mrs. So-and-So" are interested—ladies whose pleasure at being useful, as they think, to a good work, would become horror if they knew what really happens in those places, to the girl immigrant, or the dazed workingman ignorant of English speech, cheated and robbed of the few cents he lands with, then sent to some factory or mine, bound to pay part of his earnings to the boarding-house keeper and fees to a labor agent. When you come to him at this moment with Americanization ideas, you come to a man weary

and sore. You do not understand what is the matter and you don't know how to grip him. From that time he distrusts you, which drives him often into the hands of political tricksters and other propagandists who are no more his friends than they are yours. When he gets on a little, finds fellow countrymen, he forms a household group with them and sometimes creates possible living conditions for himself, entering perhaps some workers' mutual organization. We have quite a number of these in America and they are of the greatest value to the workman, wherever they are run as they ought to be. But when they chance to fall into wrong hands they can become the means of cruel exploitation of their members and organs of other mischief. In one case, men from different parts of America, belonging to a unified group of such mutual insurance societies, came to me with the books of their insurance society asking me to help them to get justice. They were in revolt against the president, secretary, etc., of the organization, which comprised several hundred small lodges dotted all over America. It had a yearly income of over $200,000. The workmen, members, at a general convention had chartered it under the insurance act as a mutual insurance society, adopting by-laws which instituted proper supervising bodies. The president of that organization, who was a United States citizen, though foreign born, has ambitions and used the organization for furthering his personal purposes. He was averse to supervision. When it came to translating the minutes, constitution, and by-laws into the English language for registration, as voted by the delegates of the workingmen's groups in their own language, he simply struck out all the paragraphs which had to do with the supervision of the moneys and other guarantees of fair dealing, and replaced those clauses with one single paragraph giving the president of the organization sole and unhampered authority to receive, deposit, and deal with the funds at his discretion. He then proceeded to suspend all dissenting supervisors. The case came before the State Insurance Department, which took the attitude more or less of Pontius Pilate, washed its hands and gave a rendering which was neither fish, flesh, nor fowl, and sent the whole thing to the civil courts, advising that the matter be attended to and put into order. Whereupon the president of the organization thought it would be wiser to arrange the matter without further publicity—which had already extended to the press, during the many months in which the workingmen spent their earnings in striving for justice—and the accounts were rendered.

To illustrate further: About two years ago I was asked by some workingmen to intervene and help in a rather interesting case in connection with the munition strikes and the demand made for embargo on all exports of munitions and other supplies to the Allies. Those men belonged to a workingmen's fraternal mutual benefit organization, of which the overwhelming majority belonged to the Eastern Orthodox

or Russian (Greek) Church, the minority—a small minority at that—to the Roman Catholic faith. At their last convention, this Roman Catholic minority, headed by some priests, got hold of the executive administration of the fraternal workingmen's organization. Here it must be said that the Roman Catholic minority of the organization hailed entirely from Austria-Hungary, and the priests, their leaders, were men practically put at their head by the Austrian consular and ambassadorial authorities in this country. The non-Roman majority hailed from Russia as well as from Austria. At that time the executive administration of that fraternal organization ordered its members—I believe some 300,000—to sign a petition to the President of the United States demanding the ordering of an embargo, in the default of which they notified him that a general strike would be declared. As far as I remember, about 90 per cent. of the workingmen members refused to comply with that demand. Whereupon they were told that in case of refusal to strike, they would be striken off the roll of the society and forfeit all their insurance benefit to which they would be entitled.

I enlisted the aid of an agent of the secret service of the Federal Department of Justice. I must say, these agents did their best to aid the workingmen, who desired to remain at work and refused to strike, but in other directions nothing was accomplished because the strike organizers cleverly shifted the whole onto religious grounds, muddled and befogged the issues—the strike-organizers gained their points by powerful political support—and the workingmen who refused to strike were penalized, and practically lost the day. What do you think is the mental state of these men today? At home in Austria-Hungary they had been persecuted for their religious faith, and here they find themselves penalized for desiring to remain peacefully at work and be peaceful citizens; here again to be persecuted for their religion.

It is a habit to accuse the foreign worker as a man of subversive tendencies, etc. Nine times out of ten he is not, and nine times out of ten he is the innocent and suffering victim of smug and clever and powerful gentlemen who use him and his troubles in their political machinations.

One great hardship of our foreign workmen here in America is connected with the foreman system, especially where the men are engaged by the foreman. The large majority of our men are not Roman Catholics, and most of your foremen are Irish. Immigrants from non-Catholic districts of Austria-Hungary are not Roman Catholic and many have abandoned that country because religious and state persecution in Austria-Hungary are one and the same. They left it with a hatred against everything Roman Catholic. Now, you give him that foreman, a good Irishman and devout Roman Catholic, to be his boss; nothing is bad enough for the "Hunkie," especially where your foreman relies

much on the shilleaghla, even though the "Hunkie" be himself a Catholic. These workmen were all soldiers, and our men in certain parts of Europe do not value human life more than the price of a cartridge. We don't think very much of fisticuff fighting, but we shoot, as your Westerners do. When that man is touched by a foreman, the spirit of the vendetta is up. It might not come out at the moment, he might not knock his tormenter out immediately, because he thinks "I am in a foreign country, I have to be more clever than that" and he tries other means. One of the most terrific of those events you had in East Youngtown, Pennsylvania, 1916. The working population there was mostly foreigners, and the matter really, as far as I understood, from workmen themselves, started from foreman trouble. Men had been beaten, and the mass of them fired into. Even a "Hunkie" is human, and a man. His patience—and he has patience to be admired—comes to a limit at last, and outbursts such as that of East Youngtown are the result.

In short, the foreign workman should be studied in the lands of his origin from the human point of view, and more searching measures taken here, from the moment he lands, to make him know the good side of America; which, in truth, somewhere does exist as he pictured it, but where that fair dream never "comes true" for him.

The Crippled Soldier in Industry

BY FRANK B. GILBRETH, PROVIDENCE, R. I.

(New York Meeting, February, 1918)

THE problem of the crippled soldier in industry is not a problem of war work only; it is a problem of industrial development. As individuals, each one of you is seeking to provide our maimed heroes with such teaching as will render them, in the shortest possible amount of time, productive and satisfied members of the community. As individuals you are interested in the organizations that are preparing to receive these men, to train them and to place them at that work for which they are best fitted.

As an organization, it is now your duty to take up the industrial end of the problem, to investigate existing conditions in the industries, to discover where the opportunities for employment lie, and so readjust industrial practice that the cripples may be utilized to their own and the community's good with the least shock to themselves or to the industries, and with the greatest amount of permanent benefit to all concerned.

We have divided industrial opportunities suitable for cripples, roughly, into three classes. *First,* such as already exist in the industries, which can be set aside for cripples only, present occupants being transferred to other work for which they can be fitted but which is not suitable for cripple work; *second,* opportunities in the industrial world that, through changes in the working equipment or tools, or through appliances attached to the cripple himself, can make the cripple a competitor of the sound worker; *third,* opportunities not existing at present in the industries, but which could be introduced for the good of the community, without placing the cripples into competition with any existing class of workers.

As typical of the first type of occupations for cripples, we have mentioned that of store-keeper,[1] of the second type that of typist,[2] and of the third type that of dental nurse.[3] The last occupation can be so arranged as to take from the overworked dentist the work of cleaning teeth; and

[1] Measurement of the Human Factor in Industry. *Report of the National Conference of the Western Efficiency Society,* May 22–25, 1917.

[2] How to Put the Crippled Soldier on the Payroll. *The Trained Nurse and Hospital Review* (May, 1917).

[3] Conservation of the World's Teeth. *The Trained Nurse and Hospital Review* (July, 1917).

after careful investigation and embodiment of the resulting data into standards, teaching can be provided that will enable the cripple to perform this work satisfactorily and profitably. In a session held at the recent annual meeting of the American Society of Mechanical Engineers for the discussion of the crippled soldier problem from all aspects, we emphasized the fact that it is the duty of the engineer to provide the new education for the cripples, that is to say, to investigate by careful measurement methods of doing work, and to formulate the One Best Way by which each type of activity should be performed.[4] By this means it is possible to eliminate waste in the teaching and learning process, and to enable the crippled soldier to get upon the payroll most quickly and most profitably.

Supplementing this duty of the engineer is a second duty, which is to investigate the industry to which he belongs in the most thorough fashion and to note the existence, or the possibility, of the three types of industrial opportunity mentioned, in order that the properly trained crippled soldier may be placed with the least amount of delay possible. The training is already insured, for not only are the foremost minds in re-education in this country in all lines of activity interested, but the great scientists abroad have offered coöperation and actual training in their schools and laboratories; notably Prof. Jules Amar, whose masterly work in re-education is soon to be presented to us in English.

It remains now to provide the work for the re-educated. Much is already being done by state and national departments, by cities and by trade organizations, but it is essential that the engineer, working as he does in many industries, start *at once* to make a survey that is scientific.

There are several methods by which this side of the problem may be attacked. *First,* by making careful records of all cripples at present employed in the industries, of the nature of the crippling, of the type of devices in use to enable the cripple to perform his work satisfactorily, of the type of the training found adequate, of the records made by these men, and of any recommendations as to the use of that type of work for future cripples. *Second,* by making a Fatigue Survey[5] in every industry, that will record all fatigue-eliminating methods and devices, since these can often be easily adapted so as to make the occupation a possible one for a cripple. *Third,* by studying all machinery and equipment in use in the industries, with the idea of inventing appliances which will enable the same to be operated by a crippled worker. *Fourth,* by classifying all occupations in the industries according to the particular faculties demanded. That is to say, listing under one head all those requiring keen eyesight, under another head all those requiring keen hearing, and under a third all those where a fine sense of touch is essential, etc. Through such

[4] The Engineer, the Cripple and the New Education. *Journal, American Society of Mechanical Engineers* (1918), **40,** 51.

[5] *Fatigue Study,* Chapter 2. New York, Sturgis & Walton Co., 1916.

a classification alone, many possible occupations for maimed and crippled have been discovered. *Fifth*, by classifying all occupations according to the amount of endurance or strength required. This classification of occupations should be made before women workers are introduced into an industry where they have not worked before, and many of the investigations necessary for placing the cripples can be much curtailed if the crippled soldier problem, the problem of introducing women into the industries and the fatigue-elimination problem are all considered at the same time, since they involve many common elements.

Another method of investigating the industries for opportunities is according to the *elements of motions* involved in the activity. Every motion may be divided into at least sixteen elements. These are: (1) Search; (2) Find; (3) Select; (4) Grasp; (5) Position; (6) Assemble; (7) Use; (8) Disassemble, or take apart; (9) Inspect; (10) Transport loaded; (11) Preposition for Next Operation; (12) Release Load; (13) Transport empty; (14) Wait (unavoidable delay); (15) Wait (avoidable delay); (16) Rest (for overcoming fatigue). The scientific method of studying these elements of a motion consists of recording the path of the motion through the micromotion method and the cyclograph method, and then arraying the resulting data on the Simultaneous Motion Cycle Chart, called "Motion Chart" for brevity.[6] Through this method an exact record of the path of the motion and of the time consumed by the motion is made, and one is enabled, through the charting, to visualize the parts of the body that are acting simultaneously and what each part of the body does during the entire motion cycle. It is obvious that from this information it is possible to transfer activity from one member of the body to another, to supply equipment that will make it possible to utilize different limbs from those previously used, to eliminate useless motions or substitute more efficient ones, and ultimately, to use the results for the selection of that type of worker best fitted to do the work according to the ultimate standard method, for placement and for teaching.

But for survey purposes it is possible to observe an activity without instruments of precision and to make some rough estimates as to how suitable it is for a cripple occupation. For example, take the first element, "Search." In many an existing operation today the searching is done both with the hand and with the eye. This is reduplication of effort, and your Secretary, Mr. Stoughton, can doubtless tell you of the wonderful work that has been done with the blind in making "Search" (1), "Find" (2), "Select" (3), and "Grasp" (4) into one operation. In applying the results of motion study in the industries, it has been possible to make this same combination through the use of cross-sectioning, and through placing materials on a fixed spot, in the proper position to be

[6] Motion Study for the Crippled Soldier. *Journal, American Society of Mechanical Engineers* (1915), **37**, 669.

grasped. Again, through the packet method, which provides for the arrangement of materials on a proper support and in the required sequence and the proper position to be transported to the next operation, it is possible to combine "Search" (1), "Find" (2), "Select" (3), "Grasp" (4) and "Position" (5), and to make of the entire five elements one operation requiring nothing but a simultaneous reach and grasp. The elements "Assemble" (6), "Use" (7), and "Disassemble" (8) can also, in many cases, be performed without the use of the eyes and with the effort involved much minimized through the use of proper desks and work-benches, chairs, arm-rests, and foot-rests. An enormous amount of fatigue can be removed on many types of operations if the forearms are properly supported. This is the case in much fine assembly work.

"Inspection" (9), is a function that may be handled by any one of the senses, and in fact is handled by the eye, the ear, the touch, the taste, and the smell in many existing occupations of the present day. This, alone, is a help in the assignment of work, since it is an accepted theory that when one sense has become dulled, the others become sharpened, either through some compensation or through a greater amount of exercise. "Transport Loaded" (10), "Preposition for next Operation (11), "Release Load" (12), these all are in many cases taken care of through gravity, or through some mechanical means of conveyance. "Transport Empty" (13), which means carrying the working member back to the place of beginning work, may be controlled so that it uses the least amount of effort and results in thè least amount of fatigue possible. Laboratory investigations have proved that there is a tendency for the empty hand to return to the work-place through a higher path than is used when the hand is loaded, this doubtless being caused by the release from tension and a natural inclination to spring up into the air without realizing the ultimate fatigue from lifting the weight unnecessarily through the higher arc. Pre-arrangement of the material, or simply calling attention to the fact, may do much to cut down this unnecessary fatigue. "Waiting (for unavoidable delay"14), can be utilized for "Rest" (16). "Waiting (for avoidable delay" 15) can be immediately eliminated, through a proper study of the operation. In this way we have again a combination of two or three elements. No individual operation need cover all these sixteen elements. Some may cover many less; a large number, during the present imperfect state of development of efficiency in most operations, have an element repeated many times. The fact remains that this method of studying an operation will immediately result, not only in calling attention to possible improvements, but also in showing opportunities for cripples to enter the work. This has been called the motion study method of attack, and in actual practice has proved itself most efficient.

There can be little doubt as to the efficiency of these various methods

for finding opportunities for the cripples in present-day industrial work. There must, however, be a question as to what will happen to the workers already in these positions, and what changes must be made in our relations with labor and in present-day classifications of the trades. Undoubtedly during war conditions many of these opportunities will present themselves automatically, as the younger men are transferred into active service and the men of larger experience are transferred or promoted to more complicated work. The entrance of women and of cripples into many trades now considered necessarily done by unmaimed men workers is already an existing condition in the industrial world. It remains rather to consider whether the returning cripples shall be welcomed in the industries and placed at the most fitting occupations with the least delay possible, or shall be allowed to enter as a matter of necessity on a competitive basis, and be placed at occupations which are not fitted for them, and shifted from place to place until the adjustment shall take place. Those who are acquainted with the psychological aspect of the problem, and who know how much the cripples need encouragement and the feeling that they are welcomed back into all social activities of the community, can realize the importance of deciding this question at once. It is simply facing a necessary solution of the problem and providing that it shall take place with the largest benefits possible to all elements concerned. The industries *must* take the cripples. The cripples *must* be put at work. The only matter open for decision now is how efficiently, and with how much satisfaction to the cripples, this adjustment can take place.

As for the necessary classification of the trades, this is a matter that was pending long before the war.[7] Those who have been interested in trade development, and have made studies of the problems involved throughout the last 20 years, must realize that reclassification of the trades is basic if this country is to attain and hold her fitting place in the world's trade.[8] Here again we have not a decision to make as to what will come, but simply as to how we will bring the necessary results about in the best method possible. The trades are, at this very time, being reclassified in order to allow the women and the cripples to come in to do that work which they are capable of doing, to the advantage of the work and to themselves, and this condition cannot and will not cease when the war closes. Because of fixed physical limitations, the cripple will have to turn out a certain amount of product of a certain fixed quality. Because of humanitarian conditions, he must work in an environment where all unnecessary fatigue is eliminated, and where rest from necessary fatigue is provided. The same holds true with the introduction of women into the

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[7] *Motion Study*, 94. New York, D. Van Nostrand Co., 1911.

[8] *Applied Motion Study*, Chapter 1. New York, Sturgis & Walton Co., 1917.

industries, where they have not formerly been. Unless proper provision for fatigue elimination is made, disastrous results will inevitably follow,[9] and have already followed where restrictions have been done away with even temporarily.[10] Again, the question of proper selection, placement, and promotion are vital at this time.[11] As has been said, "We are involved not only in the task of winning the war but of *winning the peace.*" If we are to do this latter we must provide for the new elements entering into our industries, for all practical purposes the cripple is a new element, being an entirely different man in many respects than the man who went out of the trade.

We must provide for the least amount of waste possible in the handling of this human element. A solution along these lines lies in a new form of education, that is, in teaching the one best way according to which an activity is to be done.[12] This teaching and its results will automatically provide workers whom it is easy to select, to place, and to promote.

Again, the question of monotony, so much discussed and so little understood, must be faced immediately. Monotony is not the result of repeating the same operation according to the same method a great number of times.[13] It is the result of doing work which does not occupy the attention, and, because of having nothing to hold the interest and attention, allowing the mind to follow the manual operation in an endless, tiring, deadening sequence. The remedy for monotony consists of two things. First, reducing all possible elements of the operation to an efficient habit,[14] thus giving to the mind freedom from unnecessary repetitive decisions, and second, making the work so interesting, through motion study and fatigue study, and through enlisting the coöperation of the workers, that it becomes a stimulating exercise. This is possible, is practical, and *has already been done* to the distinct advantage of both work and worker.

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[9] Industrial Liberty in War Time. An Address by Sect. of War Newton D. Baker before the Consumers' League at Baltimore, November 14, 1917.

[10] Industrial Fatigue and Its Relation to Maximum Output, by Henry J. Spooner, London Polytechnic. Co-Partnership Publishers, Ltd., London, England. Reprinted from *Co-Partnership* (December, 1916–May, 1917).

Also, *Industrial Fatigue and Its Causes*, by Prof. A. Stanley Kent of the University of Bristol, England. A Series of Reports published by Darling & Sons, Ltd., London, England.

Also, Industral Efficiency and Fatigue in British Munition Factories. U. S. Dept. of Labor, Bureau of Labor Statistics, *Bulletin No.* 230.

[11] Adequate Promotion as a Solution of the Labor Turnover Problem, a paper presented before the Brooklyn Institute of Arts and Sciences, February, 1918.

[12] The Place of the Educator in the New Education. American Association for the Advancement of Science (1917), Sec. L.

[13] *Applied Motion Study*, Chapter VIII, 158.

[14] *Psychology of Management*, 234. New York, Sturgis & Walton Co., 1914.

As to the attitude of organized labor to the admission of crippled soldiers into the industries, we cannot but believe that the Unions will be prompt to welcome the "weaker brother" back into the ranks, and to coöperate in every way possible toward his most advantageous placement just as they have been glad to coöperate in other industrial war measures. The preliminary step toward having the employer and the union agree on this matter is for them to start immediately a campaign of agreement along lines where they already agree. For example, both employer and employee are vitally interested in fatigue study, and its results benefit both alike. Both employer and employee are interested in eliminating waste in order that the largest wages possible may be paid, and the greatest amount of contentment among employees may result. Undoubtedly, when such things as fatigue elimination have been agreed upon, the agreement as to the placement of the crippled soldier will come naturally It must not be forgotten that the crippled soldier is only a specialized case of the industrial cripple returning to the industry. The latter is first an industrial worker, then a soldier, then a cripple, then again an industrial worker. The military experience may add to the capability or the initiative, and thus make the war cripple slightly different from the peace cripple, but if methods which prove successful in handling industrial cripples be applied to the war cripple no great errors will result. There is one thing besides to be considered; namely, that the war cripple has probably passed through a more awful shock, therefore the period of readjustment should be made the simpler and easier.

We believe, then, that the problem of the crippled soldier in the industries can be most quickly and most profitably solved by considering it a variation of the problem of the industrial cripple, by teaching the returned soldier the particular work at which he can be most satisfied and most profitable, and by affording opportunities in the industries, through the coöperation of those in the industries, both employers and workers alike. We further believe that it is an important duty of the engineer not only to see that the one best way is taught to the returning cripples, but that the one best opportunity is found for them in the industries.

DISCUSSION

Bradley Stoughton, New York, N. Y.—In one way, I am sorry to speak first, because perhaps by speaking of the blind worker, I shall turn aside the thoughts Mrs. Gilbreth has so well presented, because we have blind men with us always, but we are going to have more crippled men than we have ever had before, and worse crippled men. I have been in blind work for a good many years and am much interested in our Association here in New York and have visited a good many other Associations in different parts of the country. When a blind man first knows of his

affliction, he becomes most abnormally depressed. There is no sort of handicap or crippling that depresses a man at first so terribly as blindness. Generally for a month, sometimes for 2 months or 3 months, a man who is blind or who knows he is going blind wants to kill himself. In the first place, he does not want to live, and in the second place, he does not want to be a burden on his family. We have found, however, after more than 20 years' work, that if we can get a man over the first 2 months, we can generally make him a very valuable citizen. After that period, blind men are almost always the happiest of cripples. If any of you doubt it for a moment, I will get up a special excursion to our blind shop here in New York, where we have nearly a hundred men doing different kinds of industrial work, and you will find them singing and cracking jokes with another and you will find them altogether a happy lot of men; but if you go to a deaf and dumb asylum, for example, you will find on the contrary that they are not happy and they get more unhappy all the time. That is the particular message I want to spread to everybody, because we are going to have a great many blind soldiers. Now, blinded men can do many useful things. Most of them, I regret to say, are manual rather than intellectual. Most of our laboring men make brooms; many of them make baskets; many of them cane chairs. If they are of a musical turn, they can tune pianos. Almost all of them are splendid masseurs. They are most excellent telephone operators and so on. The reason for it all is that blindness brings an extraordinary concentration, and for telephone operating, for example, there is no distraction that makes you forget the number or forget to call up the number that was busy before, or many of those annoying things. It is the same way with stenography. A blind man can work one of these stenographic machines just as well as one who sees. It presses a little impression in the paper, he can draw that through his fingers and then type it on the typewriter. Now I want you to know of those things. I want you to tell everybody those things, that the information may go out and catch one or two men so that if they become blinded in battle, they are going to think of it. I want to join with Mrs. Gilbreth in asking every engineer and every manager present to bear in mind all the time how they can use crippled men, including blinded men.

Louis D. Huntoon, New York, N. Y.—The Mining and Metallurgical Society received a letter from the American Committee of Engineers in London in regard to preparing for crippled American soldiers. A copy of this letter was immediately mailed to the fifteen directors of the Society, asking for suggestions and recommendations. The following letter was received from Mr. Stanly Easton.

"I have your letter enclosing copy of letter from the Chairman of the Sub-Committee on Crippled Soldiers, London. In response to your

invitation, I have the following suggestion to offer: crippled soldiers should go back into industrial life and be put on an earning, if not a self-supporting, basis as quickly as possible, as much for their own good as for economic reasons. Having had some experience in handling men crippled in mining and affiliated work, I know that their mental and physical healing is hastened by following some interesting and gainful occupation rather than by loafing about, thinking of their misfortunes and listening to the condolences of their friends, even if they are receiving the best of care and comfort. I have found that there is some useful work for almost any crippled soldier, although I have never had a totally blind unfortunate victim to place. I have observed repeatedly that the victim of some accident, who has been very badly mutilated and who is desperately blue and discouraged, recovered his spirits and faced the future cheerfully just as soon as he got something to do that he could successfully handle. I believe the suggestion that men crippled in the National service be not discharged but kept in the army for at least a year is an excellent one, but they should be encouraged to take up their work where they left off in entering the service. If, with some strong and public-spirited organization, it is probable that such former employer can find something for them to do that will suit their impaired physical condition, particularly if some governmental or other influence is brought to bear on such employer and the military pay continued while the man is breaking into his new work. Young men, of whom our military forces are nearly entirely composed, develop rapidly along new lines when their old work is made impossible because of physical disability. I have noticed individuals who have never done any clerical or mental work gain very rapidly in this direction when an injury prevents them from continuing the manual labor which heretofore was their sole calling. Briefly my suggestion is, help these men get back into civilian life and take up their old work, or similar work, where they left it off, through the coöperation of their former employers and the government or some organization formed for such mission."

J. M. Glenn, New York, N. Y.—I desire to call attention to a paper issued by the Committee on Blindness. It is a very interesting study and can be had from the Committee on the Prevention of Blindness, which has its office in the Russell Sage Foundation Building, if anybody would like to get hold of it. It contains very valuable suggestions as to preventing blindness by accident and can be had from the Committee.

W. M. Kreglow, Palmerton, Pa.—In one instance that I can recall, a railroad man lost his leg; he has been trained since that as a machinist, and makes a better living after his injury than before. In one of our departments, the foreman at first said he could not place any

cripples, but after analyzing the jobs we found that in 20 per cent. of them cripples could do the work.

C. R. Hook, Middletown, Ohio.—The men of our plant, the superintendents in the several departments, are really giving this matter serious consideration. Especially is that true of our chief surgeon and director of employment, who has had several conferences with me on this particular subject, and we have already started to study the different positions in the plant to discover those positions into which men who are totally disabled in one or more limbs, or partially impaired, can be put. To be specific, since railroad men have been mentioned, we had a man who was a conductor of one of the freight crews, who had his foot run over and the lower part of it taken off. He had had experience as a fireman at one time and was pretty thoroughly familiar with the work of the engineer. We put him back into the cab for a couple of weeks and let him work for the engineer and then we gave him a position as an engineer and he made more money as a locomotive engineer than he did as a conductor on the ground. We also have found places in our open-hearth plant, in our blooming mill, and our bar mill department also for men who have been disabled, by placing them as pulpit operators where the operator can sit up on a platform and operate levers that run the rolls, this way and that way, and shift guards this way and that way, or turn over a device or whatever it may be. He has got to be close enough to these levers to operate them. He can sit on a stool and operate the lever just as well as the fellow who has both his legs. In the open-hearth department, we have found places for men who have been crippled in various ways, by putting them in as door lifters. They operate the hydraulic and also the electrical apparatus which lifts the doors of the furnace; and there are several things of that kind around the plant which we have already discovered.

E. E. Bach, Ellsworth, Pa.—One man who worked in our mines lost his leg and we trained him for a stationary engineer; he didn't lose much earning power in the transition.

Martin L. Griffin, Rumford, Maine.—We have to look at this matter through different eyes. There is no question about it that a cripple is not the most efficient man; he has lost a valuable asset, and we have to take into account that he has been defending his country, he has been defending our civilization, our homes, and our rights, and we have no right whatever to draw the same lines that we would at other times. We are obligated to take care of him, and, as the gentleman has said here, there are a great many jobs that men who have lost some of their personal assets can fill. We have more accidents in our line of business

than we wish we had, after complying with all the requirements of the law. Some of our men will, at times, lose their hands or their arms, but we always find employment for them. There is no question whatever that employment can be found for the soldier boys when they come back crippled, but, we shall have to change our viewpoint; we cannot select in the same way that we did before.

W. O. Owen,* Washington, D. C. (written discussion†).—Few people appear to realize that the time to reach the crippled soldier is when he is first hurt. In my own judgment, the best time to reach him is before he is hurt, by showing him what other cripples have themselves done of their own initiative, without Government support, rendering themselves self-supporting, able to bear a little bit more than their own weight, so that they may lay aside a little bit for a rainy day and some for a little fun in life as it passes by. Then, when the time comes, he recalls these pictures and they give him hope. Give a man hope that he can teach himself, so that he can carry his own weight in competition with other men, and he will work like a digger to accomplish this end, and thus train his brain and his remaining faculties to such a degree that he is of far more value than he ever was before.

I often think of what was once said to me by "O N E Best Way Gilbreth," that he could see no good reason why a man might not have at least half a dozen mechanical hands in addition to his own two—all that was required was to train his mind so that his muscles would handle and coördinate these four pairs of hands.

I have a picture of a highly trained electrical engineer who has no hands, and only stumps of arms, but he makes his own mechanical drawings, and is employed by a large electrical company as an inspector of meters, training other inspectors to do this work. He rides his own bicycle to and from work, through the densest part of the traffic of one of the large cities of the United States.

An engineer is one who makes exact measurements and records the results in terms of exact measure in three dimensions of space, and the period of time, so that any well trained engineer may repeat the experiment or the mechanical performance at will, and when a new problem comes up, may apply this same exact method to the study of the solution of the new problem. Hence it is that I have felt that it was the engineer alone who could solve the problems for the cripple and help him on his way to a self-supporting life. No one is more aware of the many subdivisions of engineering than the engineering profession itself.

It is curious that the men in this great, splendid profession fail to realize that "there is a new Richmond in the field" contending for his

* Colonel, Medical Corps, U. S. A.; Curator, Army Medical Museum.

† Received Mar. 30, 1918.

position in the center of the sun. This man, too, experiments with material and makes record of the results of what the interaction of these materials may be in three dimensional space and in measured periods of time; it is his task to study and measure the relationship between living entities and their products, and their relations to space and time; therefore I think he may be properly classed as an engineer and take his place in this great profession of yours—a new specialty engineer—the Biological Engineer.

Frank E. Sanborn,* Columbus, Ohio (written discussion†).—Advancement in the movement for the benefit of cripples, both of peace and of war, in this country has been given great impulse by the author of the paper. He has been preaching and teaching it for several years. We are indebted to him not only for his presentation of certain phases of what should be done but also for the means, the instruments of measurement.

Before this world war the industrial nations of Europe had recognized the need of something definite for the employment of the cripples of peaceful times. The war has accentuated this need and hastened these developments already started. They are way ahead of us in this and we can learn much from them, modifying it to meet any different condition of life here.

There are some statements, perhaps axioms, which we might have in mind from the start:

Work is a blessing and not a curse.

Overwork is a curse and not a blessing. By overwork is meant that amount of work of any kind which produces so great a fatigue that it is impossible for the worker to recover his former or normal energy from week to week.

"Nothing to do" is a great curse for a well, normal person. This "nothing to do" may arise from pure laziness, from too much wealth, from lack of ambition.

Any person who has a dollar is a capitalist.

Any person who is engaged in a useful employment is a laborer.

These capitalists and laborers coexist; each is the other, always was and always will be.

The material things of life are made available to more persons as the cost of the production and distribution are lessened.

Persons have more ability to purchase as their financial return for their labor and their invested capital is increased.

The more persons there are with good financial returns the better the industries of the country.

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* Director, Industrial Arts Department, Ohio State University.

† Received, Apr. 1, 1918.

Therefore each person should make as large an output as possible and receive as large a return as possible for it. These go hand in hand.

The object of scientific management is to put into operation ways and means to secure this result, applying all the known laws of science involved, conserving the individuals and increasing their happiness.

With these statements in mind, what shall we attempt to do for and with the crippled soldier? The crippled soldier is a crippled person; he was busy in some occupation before he laid it aside to fight as a soldier. He returns a cripple in many cases. He may be able to carry on his old work as well as before, and he may not.

Allied countries abroad have adopted the policy that the Government has the duty to perform of seeing that every crippled soldier, upon his discharge, is able to earn a living, if possible. While in the hospital, the soldiers have their attention called to the reëducation opportunities. These opportunities are for trades, arts, and professions. Each soldier is also granted a pension, on the policy of the same pension for the same wound regardless of the man's previous position in society; the pension varies with the kind of wound. The return is not made too large, as there is no intention to support the man in idleness, if he can be made available to society; and there is no intention to reduce the amount of his pension in case he reëducates himself and makes good earnings.

This country can do no less than to adopt similar policies: reconstruction of the soldier's body, compulsory reëducation into some field of useful endeavor when necessary, public employment bureaus for placing cripples, pensions for wounds and disabilities.

These being our policies in part, how can they be carried out? Laws must be enacted by Congress and money made available for these purposes, where no authority now exists to go ahead. The soldiers belong to the Nation and the task and duty are the Nation's. The several States will aid, without doubt.

The French have called all this work with the cripple, looking toward his rehabilitation, "reëducation," subdividing it into "functional reëducation," which includes the restoration of their natural functions to the various ailing members of the body; "prosthetical reëducation," which includes the adaptation of the various artificial devices used in replacement of natural members of the body; and "professional reëducation" or vocational education, which educates and trains the man for his future vocation.

In my discussion I include the first two under the term "reconstruction" and the last under the term "reëducation." The first might, in general terms, be said to deal with the cripple "from the battlefield to the wooden leg," and the latter "from the wooden leg to the industry."

The reconstruction belongs principally to the doctor, aided somewhat by the engineer and the physical director. The doctor has the task of

re-forming the body first. In restoring to man the use of limbs, muscles and faculties, many forms of therapy are utilized, as electro-therapy, mechano-therapy, orthopedic-therapy, massage, physical training. In this work the ability of the engineer will be of assistance in designing new apparatus of various kinds to meet the changing needs and conditions, and to make different tests of a physical nature.

The reëducation belongs to the engineer, assisted by the educator and the doctor. M. Leon De Paeuw in a recent book states that excellent results have been secured by the combination of a military man, who has charge of all purely administrative questions and superintends food, clothing, bedding, and discipline, an engineer in charge of the technical training, an educator for general educational work, and a doctor. Where occupations pertaining to farm life and soil cultivation are taught, some technical men in these lines are naturally needed. All of these men must be of broad caliber and of sympathetic and understanding nature.

It has been found by experience to be best that the soldiers who need reëducation shall not be discharged from the army until they are brought to the point of being able to earn a comfortable living. A short furlough home between the time when they are ready for reëducation and the time when they actually enter into it has been found good. The location of the various centers of reëducation should be considered carefully. Apparently too large a city is not desirable, and also too isolated a situation in the country.

By far the larger portion of the crippled men are able to carry on their previous occupation, some without any extra training, others with the benefit of such training have been able to occupy successfully positions superior to those they formerly held in the same industry.

In connection with the expression "crippled soldiers," we should not confine our idea of them simply to those who have lost an arm or a leg, and thus show marked outward evidence of their loss. The limbs may be present but incapacitated for their former service. Other portions of the body may have suffered injury so that they are incapable of full duty.

For the benefit of all, it is necessary that all crippled soldiers secure occupation. To this end a National Employment Bureau, State employment bureaus, and perhaps city employment bureaus, should be established and plans formulated so that they will work together harmoniously. They must have classified knowledge of the different industries and trades, including all the subdivisions, so arranged that they will be able to say to a given man with a given handicap that certain positions could be filled by him and certain ones could not, of the number which he might find himself inclined to follow from his natural aptitude or his training.

A crippled man should not be placed, merely from compassion, in a position which he cannot fill. He should be given work that he can do

as well as a whole man, and should receive commensurate pay. Of course, if two men, one a crippled soldier and the other not, make application for the same position, it is hoped that the crippled man would receive preference, assuming he is able properly to do the work.

It is necessary that his work be started *at once*, if not already begun. And it must be pushed. Our boys are not yet returning, crippled, in large number, but they will be coming very soon. We must be ready for treating them properly. The Allies have found it difficult to get hold of soldiers discharged before they were properly reconstructed and reëducated. We can learn from their experiences.

There are some things which can be started in preparation, and I would list them as follows:

(*a*) A bibliography of the literature on cripples, with suitable card index, by subjects and cross references.

(*b*) A card index of the different industries, with the different positions in each, and a record of the parts of the anatomy involved in filling the duties of each position. The strength, skill, training, and mental ability needed should also be noted. It may be found that portions of two or more positions might be combined and thus a new position made that could be suitably filled by a cripple.

(*c*) A card index of the different *positions*, regardless of the industrial relations, which involve the use of the same parts of the anatomy, and with it the strength, skill, training and mental ability. Then a cripple could be informed which industrial activities might be available for him.

(*d*) A card index of records of individuals already crippled and employed, giving their positions, their handicaps, their artificial aids, their accomplishments.

(*e*) A collection of motion-pictures of crippled men at work in different lines of endeavor, in home, in factory, or on the farm, showing them happily at work and self-supporting.

(*f*) Establishment, in a National museum and in State museums, of collections of apparatus for cripples. This would include all kinds of artificial members for the body, and different attachments and appliances to adapt them for use in different trades. The apparatus itself in many cases could be arranged to operate properly by the pressing of an electric button. Many photographs could be incorporated showing the various appliances in use, and even arranged as a set of moving pictures.

(*g*) Establishment at different places throughout the country of schools of vocational reëducation. These could be grouped in some manner by allied trades, by industries, by the man's available motions. The State Universities and private Universities might coöperate with the Government in giving the training. Some industries might turn over their apprentice schools with equipment to Government control for

this purpose of reëducation along the lines of their special industry. But there are many occupations for training in which the Government will have to found new schools.

(*h*) A card index of the present teachers in the various industries, properly cross-referenced. Many more teachers will be needed than those now employed in teaching industrial lines, and plans must be made to secure some from the industries and train them for teaching.

When our boys begin to fill our hospitals in France, England, and this country, then there will be needed further work of a personal nature dealing with each individual. An outline might comprise these things:

1. The imparting of hope and encouragement to the maimed soldier at as early a period of his physical recovery as possible. This will mean a few cheering words as to the future by doctors and nurses, talks by proper persons, illustrated printed stories, moving pictures of scenes in reëducation, and of cripples happily busy at home and at their employment. This mental stimulus will react favorably on the bodily healing.

2. Obtaining the record of each crippled man as given in his questionnaire (if he made one) and supplemented by his hospital record and by his hopes and ambitions as to what he would like to do. These records should be filled out in many cases with the assistance and suggestions of some sympathetic and understanding person.

3. Suitable, temporary "something to do" while he is recuperating from his wound, even while confined to his bed. Much can be done on these lines to prepare for the future vocation. This is accompanied or followed by the necessary kind of therapy.

4. The vocational training of the cripple. Care should be exercised to place him in the line of work which he desires and for which he is physically capable. While it is hoped the proper selection would be made the first time, it should be possible to change him readily to another trade or school if the first choice is wrong.

5. The scientific adaptation of the man to his vocation and the scientific adaptation of the tools and machines to the man. The first will include those appliances added to the man to supply his missing parts, to supplement defective actions and to give other artificial advantages. The second would include changes in, and additions, to existing equipment to make them workable by the maimed man. In both of these fields there will be needed the inventive faculty of many minds. Much has already been done in other warring countries.

6. The technique of the teaching of cripples will have to be developed. These crippled soldiers will be fresh from the hospitals, not yet completely restored from the nerve-racking experiences of trench, battle, and hospital. The industrial training will be largely the individual laboratory method, and but a few men should be apportioned to each instructor. The instructors will find that they will need more patience

and much sympathy for these new pupils. It is hoped that efforts will be made to find the one best way of doing each branch of the work which is taught. Such an investigation should be made with the proper scientific devices, the results of which can be suitably analysed for the elimination of unnecessary or waste motions, and of fatigue.

7. The placement of the cripple in the industries through a National employment bureau or its substitute. To do this work properly, the industries must coöperate. The cripples will be listed. Positions available must be sent as they occur to the bureau. A follow-up system must be used to keep track of the cripple.

In the various portions of the work outlined, there is some part in which each one can do his bit. Look over the different items and see if you have not some helpful information which you can furnish. Such information may be sent to the Office of the Surgeon General, Washington, D. C., as this department is looking after the reconstruction features, and some of the reëducation work. Information as to the latter work might be sent to the Federal Board of Vocational Training, Washington.

The engineers in the industries can surely make a scientific investigation of the different positions, each engineer in his own industry, with reference to the elimination of waste motions and of fatigue, or cause it to be done if he is not prepared to do it himself. It will help on the crippled soldier problem and will react to the benefit of the industry itself.

Mine Labor and Accidents

BY HERBERT M. WILSON,* C. E., PITTSBURGH, PA.

(New York Meeting, February, 1918)

THE relation of labor to the accident rate in mines is admirably epitomized by Thomas T. Read in his paper presented at the St. Louis meeting, in the sentence "Reliance for accident prevention must be upon the individual worker himself."[1]

In connection with the inspection of mines for the fixing of merit premium rates for insurance under workmen's compensation, it has been the practice of The Associated Companies to allow 60 per cent. of the credits for safeguarding of the physical hazards of the mine and 40 per cent. for the human element. By "human element" is meant that inherent tendency of the industrial worker to be careless, negligent, or disobedient, in respect to his own safety, and after that also of his fellow workman. This is a tendency not only of the laborer or of the skilled miner, but of all human beings, working or traveling anywhere.

This element of mine safety, sometimes called the moral hazard, has been admirably shown by statistics, compiled from the records of the Department of Mines of the Union of South Africa, to be due in about equal measure to the carelessness of the miner and to that of the operator. These statistics show that about one-half the fatalities in mines are due to the so-called hazard of the industry, or what is sometimes called the dangers inherent to work or misadventure. Of 2497 fatalities investigated, including over 200,000 employees, for a period of over 2½ years, it was found that 17.5 per cent. were due to faulty plant or material, fault of the foreman, or of the management—in short were due to the operator; 17.1 per cent. to disobedience of orders, carelessness or ignorance of injured persons; and 5.9 per cent. through fault of others, including fellow workmen. The fault of the operator is evidenced by failure to give proper warning, failure to inspect, failure to furnish proper equipment, and neglecting to comply with the recommendations of the inspector. That education and training of the mine operator, as well as of the mine worker,

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[1] *Trans.* (1918), **58,** 68.

is essential to any material improvement in the safety of mining is beyond question, and the system of schedule-rating insurance premiums under workmen's compensation which has been adopted by The Associated Companies takes cognizance of this to the fullest possible extent.

While The Associated Companies has accepted 40 per cent. as a reasonable measure of the proportion of accidents due to the human element, a careful study of accident causes in the last 2 years for over 2000 mines has convinced me that the human element is responsible for a very much larger percentage of accidents. J. S. Herbert, Superintendent of the Safety Department of the Cambria Steel Co., says that their statistics convince him that 93 per cent. of their accidents have had no mechanical connection, and that 73 per cent. of their injuries are chargeable to the man himself for one of several causes, usually carelessness, indifference, or recklessness.

In attempting to find a remedy for this condition, the question arises: is the class of labor employed responsible for this condition? I do not believe that it is. The class of labor employed in mines is not materially inferior to that employed in steel mills and in other large industries where the same ratio of accidents from human and mechanical causes is found. Undoubtedly, one of the prime causes is industrial unrest, evidenced in the brief period during which any workman continues in the same employment or calling. In some European countries, and in some portions of the United States, where living and housing conditions, the character of the community, the treatment of the employees by their employer, and home and social conditions are satisfactory, men continue in their employment with one concern for many years. In consequence, they become acquainted with the hazards of their calling. They are better able to appreciate their relations to their fellow workers and their superiors. They come to have a better understanding of the causes of accidents and the means of avoiding them, and the accident rate is reduced accordingly.

This brings me to the question of the relation of personnel work, in the broader sense, to accident prevention. The matter of safeguarding physical hazards, such as special methods of timbering, the furnishing of proper timbers for posting, use of mechanical post pullers, of permissible explosives, etc., are all admirable, but these methods and devices are all known, and can be applied by those who are willing to make their mines physically more safe in these respects. But the human element can only be improved by personnel work. Mere trite aphorisms, lists of "Don'ts" posted on the bulletin board, pictorial bulletins, and safety meets have their value. They are useful in arousing an interest in the worker regarding the need of safety in his employment, and concerning some of the causes of accidents; but, like everything else in life, the lesson lasts but a day. It is soon forgotten, unless it is continually hammered home, and this hammering-home process can only go so far. The mine management

gets stale on the work; safety committees cease to be active; bulletin boards and safety meets cease to interest.

The next, and third progressive step in accident prevention, and that to which the least attention has yet been given, because of its apparent cost, is welfare work, so-called. It is, in my belief, the best investment that can be made, for those who want to reduce their costs in mining. Accidents are costly; sickness also is costly; lost time for any cause is costly.

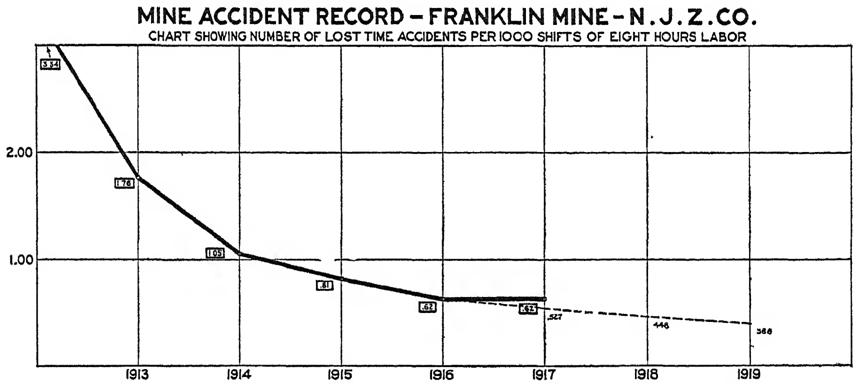
In addition to the admirable accident-prevention work being done by the state mine inspectors, through the investigations of the Federal Bureau of Mines, and by mine safety and other safety organizations, and by the mine operators and mine officials, there remains as the final field to be cultivated the improvement of the living, housing, moral, and physical conditions of the employees. There is a close relation between contentment in employment and good health, on one hand, and accident prevention on the other. A contented mind gives the worker an opportunity to think about and to know his work. It is the distracted man, the so-called "star gazer," whose mind is elsewhere than on his work, who is the most unsafe worker. Next to him is the man in bad physical condition. The ill man does not stand firmly on his feet and is likely to stumble. He wields the pick with less vigor and precision than the well man. A strong physical body and an alert, healthy mind, are among the best safeguards against accidents.

DISCUSSION

H. N. Eavenson, Gary, W. Va.—Judging from our own experience, the statement that only 40 per cent. of the accidents are caused by the human element is very low. We have adopted all the measures that Mr. Wilson recommended, such as systematic timbering, use of permissible explosives and practically everything that anybody has suggested or can think of, and even after all that has been done, done for several years, and a systematic campaign maintained all the time to reduce accidents, we still find that at least two-thirds of them are caused by the human element. I have not the exact figures in mind, but I believe the percentage will run over that rather than under. There is no question at all in my mind that Mr. Wilson's conclusion that welfare work is one of the largest points in accident prevention is sound. There is no doubt at all that if a man is well, strong, and satisfied with his surroundings, he is willing to take a great deal more interest in what is being done for him than if he is discontented and disgruntled. We have found that same thing to hold good in very large measure, and we find that the more that kind of work is done and the longer it is maintained, so that the people begin to appreciate that you really are taking an interest in them, the better the results are. The

men are more contented, they work better, they are better satisfied, and the feeling gradually grows that the company is not doing it just to get something out of them but is really doing it because it has an interest in them and in their welfare, and the mutual satisfaction engendered by that feeling is something that cannot be underestimated in any work of this kind. There is no question at all, to my mind, that welfare work and education are now the two largest factors that there are in accident prevention work, and I think that fact is gradually becoming better realized among the mining community at large. It will be appreciated more and more as those who have charge of mining work realize that this welfare work, as it is called, is not only correct from the humanitarian standpoint but that it also pays from a financial standpoint. I think that has been the experience of almost everyone who has gone into it systematically and has made a study of it in its relation to their men.

B. F. Tillson, Franklin, N. J.—I think we all agree in a very heartfelt manner with the opinions expressed by Mr. Wilson in his paper, and the accompanying chart may be of some general interest in representing



what has been accomplished in one mine through a campaign of education and coöperation with the workmen and foremen in accident prevention work. Each of the squares represents a basis of 1000 shifts of labor, composed of 8 hr. of work. The men included in this rating are the men directly responsible for mining operations; those in the ore-dressing plant, the surface plant, and the shops are not included. The rating fell from a point above the chart 3.34 in the year 1905 to 0.62 in 1916. It is rather curious, the form of this curve, and it may be expressed by a mathematical equation, $Y = 3.56 \div X^{1.065}$, the only variant from this equation being the record for this past year, which has remained about the same as the previous year, instead of improving. Of course war conditions have, in general, made it difficult to prognosticate any curves. This curve is of the form of an exponential equation closely approximating an equilateral

hyperbola, and it has followed the above equation very closely. On the basis of that we continue our line of expectations, thereby setting a standard for ourselves that, in view of the fact that we had improved a certain degree each year in the past, we could expect to improve slightly less if we continued equally energetic work and were fully repaid for the emphasis we placed upon the subject. Now this reduction was brought about by an educational campaign stimulated by a system of paying bonuses to the shift-bosses for a reduction of accidents in their gangs, thereby making it well worth their while to act as teachers in constantly instructing their men to avoid dangerous practices. The men also shared bonuses of cigars, which has been customary in many mines, at the end of each month. There is one point to be observed on the question of bonuses. Having tried many methods, we decided that the bait must not be too far away to be attractive. An annual, a semi-annual or any bonus at a distant date has little attraction as compared with a bonus at the end of the month. At the same time there is a need for furnishing incentive for a man to continue to do his best throughout a month although he may have had misfortune in the early part of that month, so that a system of pyramiding bonuses, making a monthly, a semi-annual, and an annual bonus for different rates of excellence in work produces very satisfactory results and maintains a continual interest in the need for accident prevention.

E. E. Bach, Ellsworth, Pa.—Since the idea of safety has been emphasized in industry; since each accident is being investigated; since the causes may now be determined and responsibility fixed as other than that of carelessness of the workman, and since employers really are thinking of the conservation of the life of their employees, much really useful data has been gathered upon accidents and their prevention. I know of no closer student of this phase of industrial life than the author of the paper under discussion.

It is now conceded by those who are making intensive study of accidents and their prevention that at least 75 per cent. of all accidents can be prevented. Our company succeeded in reducing its accident list 40 per cent. in the past year. It is also known that 75,000 men are annually killed through accident, and of these, 35,000 are purely industrial cases; 10,000 persons lose their sight as a result of accidents in industry.

Added to this, is the fact that each workman loses an average of $2 through sickness and pays an average of $1 per year for medical treatment. Keep in mind that between the ages of 15 and 39 one-third of all the deaths are due to tuberculosis; between 39 and 49, 25 per cent. are due to tuberculosis. The working and living conditions about industrial plants are responsible for much of this; hence industry must take its part of the blame.

Thus, from the purely selfish view of industrial efficiency, resulting from

interrupted production alone, any information which will lead to the prevention of accidents or the preservation of the health of workmen must be regarded as good business and will, at a later period, pay large dividends.

Each company must determine for itself as to the various lines of investigation that should be carried on for purposes relative to its good. I fully agree with Mr. Wilson in regard to the welfare side of accident prevention. I happen, personally, to know of one case where a man had a misunderstanding with his wife before he left for work in the morning, because of the abominably poor breakfast which she had prepared; he was on our accident list before night. Many cases of this sort have come up where domestic infelicity has influenced the life of a man and put him in a careless state.

We find that the greatest number of our accidents occur in the months of July and August; the fewest in October and February. Our investigations as to the days of the week, have covered a period of 7 years. We find that the most accidents occur on Tuesday; the second largest list occurs on Monday. They are the result of the celebrations of the previous Saturday night and Sunday night. This of course is intensified in some cases because of the celebration of holidays. Where there are many foreign people employed there are 52 distinct holidays throughout the year, aside from our own American holidays, and they are always followed by a lot of accidents.

In regard to the time of accidents; we find in our mines that the greatest number of accidents occur in the morning at 10 o'clock and 11 o'clock, and in the afternoon we find they occur at 2 o'clock and 3 o'clock. The thing we are earnestly engaged in is trying to determine why these accidents occur at this time, why most of them occur during these months, and why they occur during these particular days of the week. Last year we had all the boys and girls above sixteen in our school take instruction in first aid, preparatory to taking the examination given by the American Red Cross in first aid, and the senior class was given first aid certificates by the American Red Cross. We also insisted that our teachers take first aid instruction and qualify along that line.

C. W. Goodale, Butte, Mont.—In regard to night schools for the instruction of foreigners, the Anaconda company has done something along that line. At Great Falls we conducted night schools for two winters and about 125 of our men attended the schools and showed a great deal of appreciation of the opportunity. We had expected only 25 and had to call for more volunteer teachers. The expense was borne entirely by the company. In Butte, where there are a great many other companies operating, we hope to interest the school trustees in establishing night schools, the expense to be incurred by the school district, but

they are averse to the increased cost of instruction for furnishing teachers and paying them for night work, and probably for furnishing rooms as well, because the seats occupied by the small children would hardly be suitable for full-grown men to occupy. Though the school authorities were afraid of the expense, we believe that in accident prevention, night schools would be of great benefit to us in many ways. We have found it necessary to have our danger signs around the works printed in foreign languages, and it certainly would be a great advantage if we could get to the point where all the men employed could read these danger signs in English. I think some remarks that Mr. Eavenson made are of interest. In our review of the work in the Butte mines, also at Anaconda and Great Falls, we were somewhat discouraged to find that 1917 did not show much of an improvement in accident records over 1916, though 1916 was a distinct improvement over 1915. It is rather comforting, to me at least, to hear Mr. Tillson say that the disturbed conditions produced by the war were the cause, as we made a similar explanation to ourselves. In our own community 2300 men have passed out of the mining industry into the army, and naturally that has included experienced miners as well as experienced mechanics. Their places have been taken by men who have not had so much experience, so it is quite likely that the accident record would increase on that account. In Mr. Wilson's paper he refers to some unsteadiness; I think his expression is "The ill man does not stand firmly on his feet and is likely to stumble." Intemperance has a good deal to do with the illness of some of our men in Butte, and during some labor troubles of 1914—I mentioned this at one of our other meetings, in September, 1914—Butte was under martial law and during part of the month the saloons were absolutely closed and for the remainder they were open only during the daylight hours. The accident rate per 10,000 shifts in August was something over 11; in September the same record dropped to about 4½ and rose again in October to about 7½. This is the average of the records from probably 20 or 25 different properties, employing altogether 11,000 men. You can see, therefore, that evidence from a large number of men and a large number of properties, significantly indicates that intemperance has something to do with accidents.

T. T. Read, New York, N. Y.—I had occasion to make a statistical study of the rather complete records, over a period of a year, of one of our plants employing about 3000 men, and they brought out the same facts that Mr. Bach has mentioned; namely, that around 10 o'clock in the morninn was the maximum for morning accidents, and about 2 o'clock in the afternoon was the maximum for afternoon accidents, although these records were complicated by the fact that the men in different parts of the plant started their shifts at different times. Records cover-

ing 3 or 4 years show that August is the maximum month for accidents. As to safety work in the schools, I might remind you that Mr. Bullock of the Brooklyn Rapid Transit Co. has done a great deal of work in Brooklyn on that and has prepared some excellent bulletins and schemes of instruction. The Lehigh Valley section of the National Safety Council some time ago devised what seemed a workable plan for getting this material and distributing it to the schools, the purpose being to have the teachers take a few minutes of one regular session each week to talk to the children, also to have them write essays on the subject of safety and generally work it in as part of the regular curriculum. For some reason that plan has not yet been put into working effect, but it is on the way and in that particular case an apparently workable plan was devised. Several have mentioned the complication of accident prevention by labor turnover. I would like to inquire if anybody has any exact records. In one case I know of, a study of the records indicated that the green man was much more liable to accidents than the experienced man, but I think Mr. Fay is of the opinion that the experienced miner is more likely to become careless and be more subject to accident than the new man, and I would be much interested to learn if anybody has any exact records conclusively covering that point which, so far as I know, is as yet simply a matter of opinion.

H. M. Wilson, Pittsburgh, Pa.—I have been endeavoring to get information on this subject for some time, largely through reports from our inspectors of what they find in various mines, and I find that so far I have what seems to be quite reliable information on both sides of the question. I had always felt, as I imply in my brief paper, that the experienced workman is the safest workman, but I now feel that statement needs qualification. My opinion, as I am now formulating it, is that the experienced workman, including the experienced foreman working under old conditions, where the pressure has been for tonnage, without any special stress laid in the particular mine on questions of safety, is about as unsafe a workman as you can have. You can put over that workman a new foreman or superintendent who is interested in safety and wants to make the mine more safe, and the only men with whom he can do much are the inexperienced workmen who are ready to listen to him, to take in his lessons, and try to learn to do things in the way the foreman directs. The old-timer, who knows how, and has been mining coal for 40 years, knows a little better than the new foreman, with his modern safety notions, and is not likely to follow his instructions. Therefore, I will be glad to know if anyone has any further data on this point, bearing in mind whether or not the men are experienced men of the old non-safety school or of the more modern safety school. I have quite a distinct recollection that during years when labor was plentiful and men

were easy to get and the number of changes in the force was not so great, the number of accidents was very much less than it was after times got better and the demand for labor was greater and a great many more new men were put on. Immediately the number of accidents jumped up to more than double what they had been.

H. N. Eavenson, Gary, W. Va.—The U. S. Coal & Coke Co. and the Frick company have both maintained night schools for some years. In each case the expense is borne by the company, and the practice was to employ a school teacher for that purpose and pay him for the time he spent outside his regular school hours. We did it at Gary for about 3 years, but it is not being done now on account of war conditions. We did do it before that, the results were considered satisfactory by us and I am satisfied they consider them so in the Connellsville regions. Regarding Mr. Tillson's point, that the fall in accidents did not include last year, we had the same experience, but a little further back. In 1915 we made our best record after a steady decrease from 1907 until that time, but in 1914 and 1915 we were not doing a great deal of work, for we were not running any coke ovens and our coke production was very small in comparison with our total capacity. In December, 1916, we more than doubled the number of men we had employed, and our accidents for 1916 showed quite a marked increase over the two previous years; last year, however, we made a decided improvement over 1916 but still were not as good as 1915. There is an element of luck in these things. In counting our figures, we always include accidents and fatalities both outside and inside, and we had two fatal accidents outside over which we had no control; both happened to be on Sundays and I think both were to people who were not employees of ours at all. One was electrocuted by a high-tension wire and the other went to sleep on a larry track and was run over, but they counted just the same. In regard to Mr. Wilson's point about the experienced workman, I think the idea he has is proper, that the experience ought to be reckoned as to whether the man is experienced in years or in safety work. We have found that with the class of men we have at our mines we can usually do more with the foreigner or the ignorant man who has not been trained in that kind of work than we can with men who have worked at it a long time. The hardest men we have to deal with are native-born Americans who have been working in mines a long time; the ordinary mine foreman cannot tell them anything they don't know. We train our mine foremen the way we want them to perform their duties, and they are usually younger men than some of the experienced miners, who therefore think "It's all right to tell some of these greenhorns that, but I was in this business a long time before he was." After some years when the experienced men are men of experience in working in mines where safety conditions have

been enforced this will no longer hold. Figures compiled some years ago showed that our percentage of accidents was greater among the older miners than among the more inexperienced ones.

Geo. S. Rice, Washington, D. C.—So far as I know, the only attempt to gather statistics bearing on these factors was made by the mining department of West Virginia, which, from time to time, has attempted to get the figures of the accidents that have occurred to men of different nationalities and of different periods of experience. But the difficulty of applying these West Virginia figures is that the total number of men of the respective nationalities or experience employed in the different mines is not given, therefore it is impossible to put the results on the basis of percentages. We have to make certain assumptions. From my own observation, having had now the benefit of some 10 years' investigation of disasters, I think that perhaps what Mr. Fay had in mind is that the great majority of the great disasters in coal mines have been caused by men experienced in mining, but yet of a reckless nature who would take a chance on firing a shot that they knew themselves was dangerous. The first explosion that I personally had occasion to investigate was caused by two brothers, experienced miners, who, on an idle day (this was years ago, when the unions tolerated work on idle days), put in three very heavy charges, practically a keg of powder in the three holes. They made their fuse, we conjectured, very long, apparently with the expectation, because the mine was a small one, of getting outside the mine before the shots went off, but they were caught by the explosion when they had nearly reached the shaft, having miscalculated, apparently, by a foot or two of fuse. In one mine there have been two disasters that occurred through fire bosses, who were supposed to be experienced men, when their lights went out opening up their safety lamps and trying to relight them with matches. I think that the great disasters, at least, are largely caused by men of experience who are reckless and willing to take chances.

William Kent, Pasadena, Cal. (written discussion*).—Mr. Eavenson (page 654) says: "The statement that only 40 per cent. of the accidents are caused by the human element is very low."

Suppose that we have compiled statistics of the accidents in a certain mine or group of mines in successive years, and that the figures run as follows:

Year	1915	1916	1917
1. Accidents due to defective apparatus	40	30	20
2. Accidents due to the human element	40	35	30
3. Accidents due to causes 1 and 2 combined	20	15	10
Total	100	80	60

* Received April 13, 1918.

The mine manager might account for the reduction in the accidents due to cause 1 by the fact that new machinery had been installed and that there was an increased installation of safety appliances, and that the reduction of accidents due to cause 2 took place because the men were being instructed how to avoid accidents and were profiting by their instruction. He expects a still further reduction in the number of accidents in the year to come.

A statistician who likes to deal with percentages takes these figures and obtains from them the following:

	1915 Per Cent	1916 Per Cent.	1917 Per Cent
Total accidents	100	100.0	100.0
Due to machinery	40	37.5	33.3
Due to the human element	40	43.7	50.0
Due to the two causes combined	20	18.7	16.7

He reports that "after all we have done to reduce accidents the percentage due to the human element is steadily increasing." This little illustration shows that tabulated percentages are sometimes apt to lead to wrong conclusions. Statistics of accidents should be compiled on a unit basis, such as so many per year, per thousand men employed, or per million of tons mined.

Illness in Industry—Its Cost and Prevention

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(New York Meeting, February, 1918)

THE obligation of an employer to the State requires certain things of him as matters of good citizenship: for instance, that his workmen shall have a living wage, that child labor shall not be employed, that injuries from accidents shall not make workmen a charge upon the State, and that the laborer's children shall have opportunity for education and to become good and useful citizens. Affairs of this kind are not taken up as philanthropy, for the officials of a corporation or a large manufacturing concern may not feel at liberty to spend the funds of their company as prompted simply by motives of kindliness; but they may spend company money on such matters because it is good business.

For years, the poisonous effects of lead, phosphorus, and dust have been emphasized in books on industrial hygiene and their elimination has been urged; but the more important and everyday physiology of the workman himself has been neglected. Part of my object in writing this paper is to show how our knowledge of physiology may be applied to working conditions in everyday life.

In the interest of industrial laborers, accident compensation laws have been enacted in 33 States. This has been carried forward rapidly, because it has been shown that it pays both employer and employee. A further step is the recognition of sickness and disablement independent of accidents, not only because of their immediate cost to the worker and to the employer, but because continued efficiency in work and business depends largely upon health.

Some measure of the importance of health in industry can be gained by the knowledge that records kept by some companies which now make this the subject of careful inquiry show that the time lost by employees, through illness, is several times as much as that lost as the result of industrial accidents. It is true that accidents frequently result in permanent disability or death, but it is equally true that illness is also a cause of permanent disablement or death. Thus the chief difference is that the loss to the employee through accidents occurring in the course of his employment is now generally recognized as a cost

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which should be borne by the industry and not by the individual, while that incurred through sickness is not so regarded. Since the fundamental concept of workmen's compensation is to insure the individual against heavy losses that he is not prepared to bear, it has been argued that the cost of illness should also be transferred from his shoulders. This leads us into a discussion of compulsory health insurance, which is aside from our subject, but should be mentioned here in order to indicate that illness prevention may some day become as essential from the standpoint of operating costs as accident prevention now is.

As a matter of fact, illness in industry already has an effect on operating costs that is far from being generally realized. Whenever a man is absent from his work because of illness, it is usually necessary to have someone else take his place. The substitute, as a rule, is a less efficient workman; he makes a smaller output for the day's wages, he spoils more raw material, he requires more supervision from the foreman, who is thus distracted from more important work, while procuring and sending the substitute to the work needed involves a cost and usually a delay in the operations. When labor is abundant, it is customary to maintain a working force that is at times larger than is actually necessary, in order to avoid interruption of operations when men fail to report for work at the usual time. It is evident that this adds to cost, and now that labor is generally so scarce that industry is unable to maintain a reserve supply this cost is represented by loss of efficiency in plant operation.

The illness of the workman is not, therefore, a matter which concerns himself only, but is a source of direct loss to his employer. The cost of health supervision is not relatively large, as is shown by a comparison of the cost of health supervision in 99 industrial establishments, employing altogether 495,544 men, made recently by M. W. Alexander, for the Conference Board of Physicians in Industrial Practice. The figures vary rather widely, since some plants reported only the medical cost while the majority included the cost of clerical assistants and even of janitor, and scrubwomen. The average cost per man per year for the half million employees was $2.50, or about ¾ c. per day. Two of the companies not only give medical and surgical attention to injured employees, but furnish all the medical attention required for the families of workmen, as well as for the men themselves. In the case of an iron- and coal-mining company employing 11,000 men, the cost of giving all the medical attention required for the men and their families amounted to $11.82 per man per year, or less than 4 c. per man per day.

If, then, health is so important to industry, we must know the conditions upon which it may be enjoyed. We may consider the subject under three heads:

1. Personal hygiene, or care of themselves by employees.

2. Care of employees by employers.
3. Care by Federal, State, or municipal authorities in the making and enforcing of laws.

Fatigue

Under the first head, the principal factor leading to a high conception of personal hygiene is bodily comfort which, to a great extent, means the avoidance of abnormal fatigue. Therefore, before we can thoroughly understand personal hygiene or the care to be given by a company to its employees and their relation to the industry itself, we must understand something of fatigue, and the acts that lead up to it. In modern industry there is no question of more importance. Perhaps with a proper understanding and a study of the causes of fatigue, we may be able to practically eliminate them. Let us for a moment review our knowledge of certain simple physiological facts that relate to it.

In the living body there is constant change—metabolism. There is a constant building up process—anabolism; and there is a constant breaking down and wasting process—catabolism. Even though there is little bodily movement or exertion, still the glands are secreting, still there is a production of heat. In the muscles, particularly, such chemical changes are constantly taking place. Every exertion and muscular contraction causes the expenditure of energy. Every muscle contains in itself latent energy in fuel to be converted into mechanical energy and heat. This fuel is supplied from the blood and is in the form of sugar (dextrose, $C_6H_{12}O_6$) or animal starch (glycogen, $C_5H_{10}O_5$) and fat.

The living substance of muscle has the power of burning up sugar. In this process, lactic acid and ultimately carbon dioxide and water are formed. Thus, dextrose changes to lactic acid

$$\underset{\text{Dextrose}}{C_6H_{12}O_6} = \underset{\text{Lactic acid}}{2C_3H_6O_3}$$

and the lactic acid is finally broken down into carbon dioxide and water. Muscle is made to contract by stimulation. This stimulation is through impulse, from the brain or other parts of the nervous system. It may primarily arise from the will, and secondarily from heat, from cold, from electricity, or from other causes. When a muscle contracts, more oxygen is used and more carbon dioxide is discharged than when it is resting. A normal resting muscle is alkaline, but after a number of rapid contractions it becomes acid in its reaction.

The materials for building up the blood tissues are carried to the various portions of the body by the blood stream and the products of waste are carried away from the tissues by the same means. The oxygen necessary for combustion is carried by the hæmoglobin in the blood to the tissues. It there gives off some of its oxygen, and the blood takes up carbon dioxide, which it carries back to the lungs to be eliminated. The

liver normally forms sugar and animal starch. Muscle tissue is capable of storing up in this form much of the sugar brought to it.

In some respects, the development of energy in the body is analogous to the development of steam in a boiler or the operation of a gas engine. There must be fuel, oxygen, and ashes, or waste. From these facts it is obvious that muscular energy depends largely upon three things.

1. The amount of fuel stored and the ability of the system to bring it into use.

2. The ability of the system to furnish oxygen with which to burn the fuel.

3. The ability of the system to carry off waste or other toxic substances.

Conversely, fatigue is due primarily to the failure of the system to perform properly one or more of these functions.

Storage of Fuel.—Proper exercise increases strength. Proper use of a muscle increases its power for work. Through exercise a muscle becomes larger and has a greater capacity for the storage of fuel. This alone, however, does not account for the increase in strength, for the quality of tissue must be taken into consideration; and also that through repeated effort the nerves respond more quickly to stimuli. The capacity of the liver to store fuel (glycogen) must also be taken into consideration. This depends partly upon the size of the organ, and partly upon its condition; a diseased condition or functional disorder of the liver which interferes with the storage has to do with fatigue.

Insufficient storage of fuel may also arise from a lack of material, and under this head would come (1) lack of sufficient food, (2) improper feeding, *i.e.*, feeding of food that lacks sufficient nourishment, (3) indigestion of food, and (4) lack of assimilation of food. If fuel is lacking, energy must also be lacking. If one does not have sufficient food, he cannot store enough energy; or if the food, though sufficient in quantity, is not of the proper kind or quality, he cannot gain from it the desired energy.

Food should be regulated according to the demands of the body, to make a properly balanced dietary. It has been shown that the system can change one food into another; and excess of one kind of food is probably converted in the system into others. But physiological tests have shown that a mixed diet is best for the needs of the system. The body is very adaptable, but we should not put upon it unnecessary alimentary burdens. Pavlov has shown that the secretion of the gastric juice depends largely upon the character of food and on appetite. This also relates to the question of the wise selection of food.

After food reaches the stomach there is much needless waste, particularly of the sugars, due to fermentation in the stomach. The sugars are split into acids before reaching the tissues and so are partly lost for energy. The fermentation is due to two causes: (1) a lack of gastric

juice, and (2) an excess of bacteria. A lack of gastric juice, and therefore indigestion, is due to an improper selection of food, to a disturbed mental condition (anger, grief, worry) or to reflex disturbances of the gastric nerves, from chronic appendicitis, etc. Or it may be due to an excess of bacteria, from fermented or putrid foods, or to the addition of bacteria to the food from unclean mouths and bad teeth, or from dirty hands. Sometimes the food in lunch baskets, such as yeast bread and milk in coffee, undergoes more or less fermentation before it is eaten. Overeating and rapidity of eating also affect digestion, and therefore promote fatigue.

Utilization of Fuel.—Fatigue is caused by anything that interferes with the carrying of oxygen to the tissues. This may be a diminished amount (1) of oxygen in the atmosphere, (2) of carrying power in the blood, (3) of lung capacity, or (4) interference with the circulation of the blood.

The two factors which relate especially to diminished amount of oxygen in the atmosphere are bad ventilation and altitude. The main effect of bad ventilation, especially where there are a number of people in the room, is to increase the humidity. From diminished oxygen, altitude produces fatigue. Experiments in mountain climbing have proved this.

There is a great difference in people as to the number of red corpuscles in the blood, and therefore in its oxygen-carrying power. Some people have only half as many red corpuscles as others. Leaving out the question of loss of blood, anemia is produced by a variety of causes, among which are deficient light, insufficient iron in the blood, insufficient variety in food, irregularity of the bowels, metal poison, such as lead, and is sometimes a sequel of disease (particularly malarial or infectious disease). The most frequent and potent cause is probably focal infection. A matter of particular importance to those in the iron and steel industry is the fact that the oxygen-carrying power of the blood is very much diminished if there is any carbon monoxide in the air breathed by the workers. This gas combines with the hæmoglobin and injures the oxygen-carrying function, thus producing a very deleterious effect upon the men.

Anything that interferes with the general circulation of the blood, such as heart disease, tight clothing, or the condition of the body, causes fatigue. Where there is diminished lung capacity, as in tuberculosis of the lungs, there is interference with the oxygen-carrying power of the blood. In heart disease, the blood is not properly pumped through the body. In obese persons the greater distance the blood has to travel makes the heart pump harder. Tight clothing directly interferes with the circulation. Age, sex, climate, and seasons also have much to do with the circulation of the blood, and therefore with fatigue.

Elimination of Waste.—The third great cause of fatigue is poisoning by accumulated waste in the muscles or poisoning by toxic substances. This accumulation may be due to too rapid formation of the products of waste, or it may be due to the inability of the blood or system to carry away the waste products. If the nerve of a muscle is constantly stimulated, the muscular contractions become smaller in extent and finally cease. The muscle is then said to be fatigued. The sugars and glycogen, fats, and even protein, are burned in producing energy, and leave wastes which are deleterious and fatigue-producing. Unless eliminated, these materials act as poisons. When a muscle is fatigued, there is more to be considered than the local poison, because the products of fatigue pass into the blood and fatigue all parts of the body, including the nervous system.

Other poisons besides those generated in the muscles produce fatigue. Fermentation in the intestinal canal produces poisons which have a fatiguing effect. Thus indol, and possibly other substances, have been proven to induce fatigue. Indol is found in the large intestine as the result of bacterial putrefaction. It is eliminated in part from the bowels; but is in part absorbed in the blood and subsequently eliminated in the urine, in the form of indican. As indol is produced by the fermentation of certain kinds of albuminous foods, diet is again an important factor. That the products of waste in the intestinal canal should be rapidly excreted is self-evident.

Personal Hygiene

Taking up first matters of personal hygiene and the care of the individual, the things to which a workman should pay particular attention are: Regulation of his meals as to the amount, character and mastication of them; the amount and character of drink; hours of rest and sleep; ventilation of rooms; personal cleanliness; clean clothes; washing of hands before meals; brushing of teeth; daily washing of feet; proper fitting of shoes; amount and kind of clothing; care of the eyes, ears, and nose; regularity of movements from the bowels; regularity of work, and the cultivation of cheerfulness. The mind has much to do with the body, and especially with tissue changes and secretions.

But the question arises, just how important are some of these matters that I have mentioned? Are they all really under the control of the workman? And can he adjust them, even if he has the education and the desire to do so? It is impossible in this article to take up every one of these subjects, but as illustrations, two may serve our purpose. Let us consider the importance of washing the hands, particularly before each meal.

To Oliver Wendell Holmes, and to Ignaz Philip Stemmelweis, we owe the beginning of our knowledge that disease is carried by the hand.

They demonstrated that puerperal fever and erysipelas were carried in this way, and Lord Lister started us on the road to its prevention. Today we know that most disease is carried by contact with the body or with its secretions. In the beginning of Listerism, sprays were used in surgical operations to prevent infection by dust, but these were gradually abandoned. As aseptic practice progressed and the wonders of modern surgery were unfolded to the world, it became more and more and more ever apparent that hands carried disease. Perhaps the greatest advance made in surgery was the wearing of sterile rubber gloves by the operator and his assistants. For surgical purposes, ordinary washing of the hands does not free the hands from bacteria, nor will disinfectants do so afterward. Even after scrubbing and the application of alcohol, bacteria are still present.

The accepted method of testing whether or not the hands are free from bacteria is the passing of a sterile thread across the hand to catch any germs that remain upon it, and cultivating these germs upon gelatine plates. Such experiments show that there is no known method of perfect disinfection and cleansing of the hand. A culture test for bacteria on the hands after washing without using a brush shows a relatively high count; but if a brush is used, more particularly if the hand is afterward rubbed with a rough, sterile towel, the bacterial count is much smaller. Fortunately for us, septic conditions do not arise when the bacteria are very few in number; infection depends upon the number and virulence of the bacteria.

Perhaps the most striking illustration of infection caused by the handling of food is a case that has recently appeared in the daily press. When Commissioner of Health of New York City, my attention was called to a certain cook named Mary Mallon, or as she was called in the newspapers, "Typhoid Mary." Mary had lived with a number of families. It was noted that in whatever family she lived some one soon became ill with typhoid fever. The physician who had noted this, Dr. Soper, found that 26 cases of typhoid had occurred in these families. Under the power granted to the Board of Health for the preservation of health and the protection of the public, she was removed to the hospital for observation, and it was found that some of her ejecta were almost pure culture of typhoid. She declined to undergo any operation; and as other treatment did not cure, she was deprived of her liberty as a menace to the community. In this course, the Department of Health was sustained by the courts. But the following administration, upon her promise not to ply her occupation as a cook, gave her liberty, and for several years nothing was heard of her. In January and February, 1916, at the Sloane Maternity Hospital, 25 cases of typhoid fever occurred. A careful inquiry as to the cause of the outbreak led to the discovery that Mary Mallon was the cook. The only way in which she could

convey the disease was by contaminating the food through failure to cleanse her hands properly.

If disease is so easily acquired from soiled hands, what is the lesson we are to learn? Workers should have facilities for washing after going to the toilet. Particularly they should be encouraged to wash their hands before taking their lunch from the basket. Even though not pathogenic, the bacteria carried to the stomach from unclean hands may cause trouble. But this is not the whole story. An observer at a public hearing of the New York State Workmen's Compensation Commission, noting the victims of accidents as they appear there, would be impressed with the large number of deformities of fingers and hands due to infection of wounds. Case after case has come before the Commission, where such poisoning has resulted in necrosis of bone and made necessary its removal; or tendons have been divested of their sheaths and become fastened to the tissues and are no longer able to operate; or the muscle itself has been destroyed by an abscess; or nerves have been ruined, causing paralysis; or joints have become ankylosed and will not bend. As a result, the fingers and hands become deformed, twisted, and useless. Thousands of dollars in compensation have been lost, and many a good workman has been incapacitated for life not measurable in dollars. Clean hands and clean skin would help to prevent much of this infection.

Let us take a second simple illustration. That of mouth hygiene and brushing of teeth. The softening effect of the saliva on food, the comminution of chewing as well as the obtaining of taste and flavor which helps secretion of gastric juice, are all important. In addition, the direct chemical effect of saliva upon the food must be considered, preparing as it does the food for absorption. Food hastily swallowed in chunks or in an indigestible form frequently produces a lump-like feeling in the throat, and the effect of this lack of chewing carried to the extreme is illustrated by the convulsions which occur in infants who have swallowed a piece of apple, meat, fruit skin, or other food of like character. Food can be properly masticated only if the teeth are in a healthy condition. It follows that good teeth are desirable, and a factor in energy. One eminent medical authority has stated that decayed teeth are even more harmful than alcohol. But the harm of decayed teeth and unclean teeth is not so much the difficulty encountered in chewing as the fact that they make an unclean mouth, and may produce abscess.

It is only recently that much attention has been paid to this latter result. It is growing in importance in the minds of physicians. In the practice of their profession, physicians find among their patients many persons who suffer from an infection that is confined to one spot in the body, focal infection, but that is the cause of, or relates to, general disease of the system. By far the most frequent location of such infection is

in the mouth or throat. Decayed teeth, abscesses, and necrosed bone the result of such decay, often affect the whole body, and even when not the primary cause intensify and prolong disease.

We now know that many cases of rheumatism, *arthritis deformans*, tuberculosis, various forms of heart disease, and disease of other organs, arise from a tonsillitis or some other diseased condition of the mouth or teeth. But even though local disease may have such serious consequences and be the origin of dangerous and frequently fatal disease, to my mind another sequel of an unclean mouth is of equal importance.

A study of the microörganisms that inhabit the mouth shows that various disease-producing varieties may inhabit it; at least 50 different forms have been found there. Many well known species, some of which occur only in the mouth, are associated with disease of other parts of the body. The mouth always contains some bacteria, sometimes only a few species, sometimes many; sometimes few in quantity, sometimes in vast numbers. In pyorrhœa, which loosens the teeth and is accompanied by an exudation of pus from the sockets, millions of microbes are found in the pus. Swallowing these bacteria, especially by having them mingle with the food in the process of chewing, may be very harmful. If there is not sufficient gastric juice to kill them, they produce a fermentation of the food, and then, passing out of the stomach into the intestine, produce poisonous products of decomposition. These, on absorption, produce bodily fatigue and lower resistance to disease. Much of the sour stomach, dyspepsia, and other stomach troubles from which people suffer, are due to contamination of the food by bacteria from unclean mouths. In the many experiments and observations made by Dr. Beaumont in connection with his patient, Alexis St. Martin, he noticed that pure gastric juice would often keep indefinitely, but if mixed with much saliva it quickly spoiled.

We are careful, especially with children, that water be boiled, milk scalded or pasteurized, and food generally well cooked in order to destroy bacteria. If food be carefully selected and prepared, danger from that source is reduced. But all this care may be in vain if the food becomes contaminated in the mouth. Such precautions would seem of little value unless the teeth be brushed and the mouth cleansed and disinfected both before and after each meal. Of the two, it seems to me that cleansing before meals is the more important. Still another thought in this connection is: if food, sugar for instance, that enters the stomach undergoes fermentation there and is split up into its constituents, some energy is lost to the body; for it is by this very splitting up of food within the muscles that energy is produced.

How do bacteria get into the mouth? Some enter with the food; some inhabit the mouth and multiply upon the remains of food left between the teeth; many enter with dust, while breathing, particularly

the dust of the street; still others get into the mouth from the hands. Is it too much to hope for that in the future every workman will not only have a proper place to eat his noon meal, but will also wash his hands and brush his teeth before he eats it? It seems to me that it would pay well from the standpoint of lessening fatigue for every worker to use a toothbrush before every meal, to have one in his locker and use it at noon. Yet where is this the case now? Still, I confidently expect that in a few years this will be common practice.

Care by Employers

Leaving these matters of personal hygiene, I will endeavor to enumerate those subjects that may be considered by those in charge of industrial establishments as follows:

Prevention of accidents.
Drinking water supplies.
Washing facilities.
Laundries.
Lockers.
Toilet arrangements.
Drainage and sewage disposal.
Disposition of garbage and rubbish.
Care of stables and animals.
Heating work places in winter.
Cooling work places in summer.
Ventilation.
Overcrowding
Dust, gases, and fumes.
Periods of rest in working hours.
Education.
Relief funds.
Compensation.
Lighting.
First aid.
Hospitals.
Trained nurses and social workers.
Physical examination of employees.
Lunch buckets and lunch rooms.
Commissaries (bread, meat).
Milk supplies.
Flies, mosquitoes and vermin.
Clean mills and yards.
Housing.
Gardens.
Rest and recreation (other than in working hours).
Transportation.
Insurance.
Pensions.
Saving and investing.

To give the reasons why each of these subjects should be considered would fill a volume; let us consider only one as an illustration.

What reason, for instance, shall we give a manufacturer for the installation of a proper drinking-water supply? How shall he justify the expenditure to the stockholder? As a basis for the consideration of drinking water supplied in connection with industrial plants, it is necessary to study the physiological uses of water in the human body, that is, the effect of water on secretion, excretion, temperature, energy, and other body processes. Water is a natural constituent of the body. Normally it comprises about two-thirds of the body weight. In chemical combination it enters into the substance of the tissues; they are all largely composed of it in varying degrees. It is the main ingredient of the fluids of the body, and helps maintain their proper degree of dilution.

A food may be defined as a substance taken into the body for growth, for renewal, for energy or work, or for the production of heat. Because water thus enters into the structure of the various tissues of the body, it must be classed as a food, though it is not food in the sense that it liberates energy. The great importance of water is shown by water starvation. People may live many days without food, but they cannot go long without water. If there is insufficient water in the body, all secretions are lessened and there is dryness of the membranes and change in the functional activity of various organs. Thus there is lessened digestion and absorption of food. Intestinal excretion is retarded; abnormal products are absorbed; there is lessened excretion and increased friction.

Water is nature's great solvent. Taken with food it increases the utilization of food. It aids absorption of food and carries nutrient material through the medium of blood and the lymph to the tissues in the various parts of the body. Solution is one of the essential steps in digestion. There is widespread belief that to drink water with meals is injurious. On the contrary, one of the most common faults in eating is to neglect to take sufficient water with meals.

We may determine the amount of water necessary to maintain the system in a normal healthy condition by a study of the amount lost through the kidneys, the skin, the lungs, and the bowels. In general, the average total of these losses in an adult is five pints. This amount must be taken daily. Allowing a pint and a half of water to represent the average water content of the food eaten, the remainder, three and a half pints, about seven glasses, must be taken as drink in some other form. These figures vary greatly according to the weather and work. Hot weather and exercise increase the demand for water.

Besides carrying food in solution to the tissues, water also carries waste away. Not only is there a building up process by absorption of food, but there is also a constant wasting process resulting from the production of heat and energy. These products of waste must be rapidly eliminated or they may have a fatiguing effect. They are carried away by the blood stream to be eliminated principally by the lungs and the kidneys. If the wastes from muscular energy-lactic acid and carbon dioxide accumulate, they poison the system and energy is diminished. This accumulation is sometimes due to a lack of water in the system from not having taken sufficient drink.

The blood tends to maintain its equilibrium. If more water is taken than is needed, the kidneys and other channels of elimination work faster; the water is more rapidly eliminated and carries with it more waste. Water thus increases elimination and secretion. Absorption of water increases the fullness of the vessels and this promotes secretion. When taken into the stomach, there is always in addition some increase in the

secretion of the gastric juice. There is also increased motion of the muscles of the stomach and the intestines. Besides the functional secretion of the various organs, there are many membranes which must be kept moist to avoid friction. Among these are the linings of the joints, the coverings of the tendons of the muscles, the coverings of the lungs and the coverings of the intestines.

The normal temperature of the human body is 98.6° F. in all seasons and in all climates. Any rise in body temperature disturbs the normal functions of the various organs of the body. While a certain amount of heat is produced in glandular and other structures of the body, the muscles are the principal source of heat production. Loss of heat which accompanies loss of moisture takes place chiefly through the lungs and the skin. In active exercise and muscular labor, heat is rapidly formed, and, if not lost by perspiration and by exhalation of moisture from the lungs, it accumulates and the body temperature rises above normal; the individual becomes feverish. This is not infrequently the case in humid days of summer, because radiation and evaporation are largely retarded by a high percentage of humidity in the atmosphere.

Recent investigations tend to show that the unhygienic condition of crowded workshops and of schools and the lowered vitality of workers and school-children are due to increased body temperature resulting primarily from an accumulation of moisture in the atmosphere.

Water not only regulates the degree of temperature of the body but acts as a distributor of heat, carrying heat from one portion to another and equalizing the temperature of the body.

The temperature of water affects its attractiveness; water that is lukewarm is not palatable, and ordinarily people will not drink a sufficient quantity of it. The temperature of the water also affects health; iced water, if taken in large quantities, frequently producing cramp. While water should not be iced, it is well in summer that it should be cooled. The temperature should be about 50° F. Cold water of this character stimulates the heart. It also somewhat relieves the internal temperature. Imbibing a sufficiency of water removes thirst; thus the drinking of water probably tends to lessen alcoholism.

Many cases of dysentery, diarrhœa, typhoid, and some cases of indigestion and intestinal disturbances arise from bacteria in water. Of the various methods of typhoid infection, the drinking of polluted water is the cause of by far the greatest number of cases. Asiatic cholera is almost exclusively a water-borne disease. In addition, water may carry worms and other animal parasites.

Disease may also occur from drinking cups being used in common. Medical researches show that some of the most serious diseases can be communicated through the common drinking cup. To remove this danger, sanitary fountains are constantly being installed. To encourage

adequate use of drinking water, it should be attractive; it should be close to the worker; it should be wholesome; the temperature should be regulated; the common drinking cup should be abolished and sanitary fountains should be used instead. It is necessary that these should be properly designed, since some types now in use are almost as likely to be a source of infection as the common cup. Lead pipes should not be used for the distribution of drinking-water supplies.

Review of Work in Iron and Steel Industry

To discuss all the other topics from the physiological standpoint in similar detail would require too much space, so I will conclude with a brief review of what has been done along these lines in the iron and steel industry, with which I am associated.

Much has been done in the installation of basins and showers and in the erection of dry-houses. In many places these have had the widest use, a large percentage of the employees bathing daily. Here again we cannot adequately estimate the good derived. But we do know that such facilities enhance one's self-respect and the respect of others. The opportunity to wash before going home makes the work of the home less burdensome, and cleanliness of the hands is of especial importance because hands carry disease.

Shower baths affect the circulation of the blood, not only in the skin but in the whole body. They produce a redistribution of the blood in the body and for the time being there is an actual change in the blood itself. They eliminate more rapidly the products of waste and so constitute one of the methods of relieving fatigue. Cold showers increase capacity for muscular work. A shower bath removes the waste products from the skin and makes one less liable to harm from a change in temperature. It reduces the heat of the body, especially on humid days when the body temperature may rise above normal. Incidentally, I would mention that the roller towel has been abandoned in a large number of plants.

Many new toilets of modern construction have been built and hundreds of old privies have been abolished. Especial care has been given to the exclusion of flies and the prevention of pollution of the soil. There have been many improvements in the disposal of collection from pan privies, especially by incineration or in septic tanks. Much pollution of streams has been done away with. Thousands of dollars have been spent for drainage, particularly of back alleys and streets. This drainage has also had a very beneficial effect in the prevention of the breeding of mosquitoes and prevention of malaria.

Better methods of collection of garbage are constantly being installed, with frequent periods of collection. Much has been done in the

way of educating employees in the use of garbage cans and the necessity of keeping the contents covered, in order to prevent the carrying of bacteria by flies from the can to the table. Toward preventing the breeding of flies much has been done, especially in mining camps and villages, by the prompt removal of manure and by making stables more sanitary. Education by circulars explaining the danger of flies as carriers of disease we believe has accomplished much.

The cooling of work-places in summer is now being considered in many plants, and much is being done to make heated work places more comfortable, thus preventing heat stroke.

Thirty years ago, according to English statistics, nearly all who breathed dust from grinding steel and stone, died sooner or later from tuberculosis. Such dust has been entirely eliminated from certain mills in the industry. Air conditions have been much improved by the elimination of the hydro-carbon series and other gases produced by open fires where combustion is incomplete. These gases are now carried to the outside of the building. Much improvement has been made in the heating of plants in winter by fresh air brought from the outside, filtered, warmed and distributed to the various parts of the building to be heated. This insures a good supply of air free from dust and gases.

How often have men fallen upon fruit skins or the remains of luncheon thrown upon the ground, or have stepped upon a plank on which a rusted nail has been sticking out! Perhaps more has been done in the making of clean yards than in any other direction. It is also to be noted that the psychological effect of pleasant and clean surroundings has an excellent effect upon the workmen. Beauty and order are persuasive everywhere, and few people can resist them.

Progress in first-aid has been so wonderful that the steel industry is now leading the world in this line of welfare work. The reduction of septic cases, in some places from 50 per cent. to 0.1 per cent., speaks volumes. Nowhere else in the world has such provision been made for the care of employees who are injured. The emergency hospitals which have been provided near mine and mill stand today as examples for the whole world. They have materially aided in reducing human suffering. Many lives have been saved, much has been done to prevent fatal termination, by prompt care and by the knowledge on the part of the injured workman that such care is the best that can be obtained.

A rest farm for the wives of employees who are in poor health has been established. This farm is under the care of a physician and a nurse. The support given settlement houses and the employment of trained nurses have done much toward keeping the companies in sympathy with employees and replacing despondency with sunshine and gladness. These trained nurses have given their attention to the women and children, particularly babies. Their duties include the weekly

weighing of babies, teaching mothers how to dress and undress them, how to modify their milk, the guidance of expectant mothers and nursing them during confinement, the care of children, school inspection and other things too numerous to mention. Domestic educators have taught them how to clean house and the essentials of good housekeeping.

What the race will achieve in the future depends much on the conservation of the health of the children of the nation and in the education of these children. Many efforts have been put forth in the industry, for the prevention of disease among children. The establishment of playgrounds is a step in this direction. Play is essential to the education of a child, and these playgrounds promote health, education, morality, and happiness. They promote health by the effect of sunlight, of fresh air, of exercise on body processes, and by inducing appetite and healthful sleep. At many of the playgrounds certain accessories have been provided which aid both in education and in health, such as drinking fountains, wash rooms, and water closets, and teachers have been provided to instruct in play and in the use of these accessories. Club houses have been erected, and much has been done to provide recreation for all ages.

All energy being derived from food, good food is then of great importance. Some plants have provided dining rooms and restaurants, with freshly and properly prepared and well selected foods, furnished at the lowest practicable price, served under cheerful and pleasant surroundings. To prevent ptomaine and toxic poisoning, commissaries are often essential in order that food may be properly protected from flies and kept from spoiling by means of refrigerators. As with milk, they also fix the standard of quality.

Many a man has been kept awake by a crying child, and injuries have happened from the worry over the sick child at home. Such conditions have been done away with in certain places by furnishing certified milk at a reasonable cost, some companies having herds of cows for this purpose.

Good housing is essential to both health and contentment, because it is at home that the workman builds up his strength to perform life's duties. Much has been done in the erection of excellent houses on healthful and sanitary sites, rented or sold at reasonable rates. Many have all modern conveniences.

Construction camps have been improved. Some of recent design have the appearance of a tuberculosis sanitarium and are just as good in construction.

Of distinct economic value has been the encouragement given by employers to those living in mining and industrial villages by fencing in plots for gardens, assisting when necessary in plowing and fertilization, and stimulating the employees and encouraging them in thrift and

industry by offering prizes for the gardens. These gardens reduce the cost of living—some yielding vegetables enough for the family and also a surplus for sale—and they promote health by bringing the members of the family into the fresh air and sunshine. They mean cleaner yards and better care of drainage and waste, thus preventing odors and the breeding of flies and mosquitoes. They provide a greater variety of food, for many workmen eat too much meat, and an excess of flesh diet is not conducive to the best work, growth, or health. They tend to abolition or the confining of domestic animals. They promote morality, keep the owner from the saloon and promote his own self-respect. They help make homes and have a refining influence on the family.

DISCUSSION

Dr. E. E. Southard,* Boston, Mass.—As Director of a Psychopathic Hospital, I am a sort of "voice in the wilderness" speaking to mining engineers. I suppose that I am here because Major Gilbreth had prevailed upon me to speak on a kindred topic before the mechanical engineers at the annual meeting of their Institute.

You might wonder why a psychopathic hospital, a state institution for the first care of mental cases and especially for incipient, acute and curable cases, should have any part or lot in the industrial problem. We have obvious contacts in our institution with the retarded and exceptional children of the schools, with the defective and non-defective delinquents of the juvenile-court and reform-school groups, with all manner of problems of the mentally sick child, youth, and adult—but what contacts have we with the industrial problem?

I must confess that when in 1912, the Boston Psychopathic Hospital was opened, I did not see this industrial problem in a psychopathic setting at all. I quickly found myself associated with experts in the venereal disease question, the alcohol propaganda, the criminologists, the charity and social workers; and very soon public conferences were held upon many of these matters in their psychopathic hospital relations. The problem of industry did not at once arise in our bailiwick.

Shortly, however, we began to get cases referred to us for mental tests and examination as to mental disease from the Industrial Accident Board of Massachusetts; and a host of problems concerning damages, allowances, and compensation had to be looked into with the tests devised by Professor (now Major) Yerkes, along the lines of the Binet tests.

Another similar but absorbing group of cases that come to the Psychopathic Hospital is that of the occupation-neuroses. But aside from the Industrial Board group and the occupation-neurosis group, interest

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began to develop in the relation between unemployment and mental diseases. I can do no more than hint at some of the results already published or in process of publication concerning the problem. We found in going over 100 cases carefully examined in the out-patient department—cases in which unemployment was the major and outstanding feature in the social situation—that there were three main reasons for the unemployment. Bear in mind that the group is a selected one, the persons coming to us referred by some physician or by some hospital or other social agency for determination as to mental disease. The statistical results accordingly are probably not at all what would be obtained from a study of the mental reasons for unemployment in a group of miners, for example.

Not to use technical terms, the first main reason for unemployment in our group of cases was feeble-mindedness; the second, what one might term moodiness or a tendency to nervous ups and downs; and the third main reason was what might rather inadequately be summed up in the phrase "queerness" or peculiarity. If I were in Boston, I might speak of the unemployed as morons and manic depressives, or as victims of *dementia præcox*, but here in New York and in this company, I might perhaps get on better by speaking of them as the feeble-minded, the moody, and the peculiar.

As to the feeble-minded, which occurred in 35 instances out of the 100 under investigation by my former colleague, Dr. H. M. Adler, it ought to be very simple to eliminate them from such works as the Institute of Mining Engineers has to deal with. At all events, the United States Government is doing something like it with the Army. Major Yerkes, who is in charge of the work for the National Government, has, with his associates, devised tests for English-speaking and non-English-speaking recruits. Under the exigencies of war, group tests have been devised which ought to be, with suitable modifications, applicable to the miners and employees in great industrial works. The work after the war for the mining and other industries ought to be exceedingly inexpensive. I regret to have to say so, but psychologists with a great deal of training can be hired for very little money—it is extraordinary for how little money you can secure a psychologist. Perhaps you might even get them to come to you for nothing, so eager are they just now to show what they can do!

As to the moody persons, they occur in but 22 instances in the 100 under review. Probably you all know the type. These persons are not inadequate in the sense of feeble-minded, nor are they peculiar. They are persons who are often greatly liked or loved by their fellow-workmen, who understand their ups and downs better than the employer or the personnel man. Though they are subject to variation in temperament such that they are at times over-busy or at times subject to "blues,"

these persons can be fitted into industrial work if only the chiefs can see into their individual problems to any extent. What we are endeavoring to call the "empathic index" is very high for these people, that is to say, the ordinary man in the street or in the mine sees into the problem of the moody person and sympathizes with him, just because he himself also experiences to an extent very similar ups and downs, though not amounting to the morbid degree shown by the real victims of disease. All of which means merely that the more the employer or personnel manager can see into the problem of the individual, the better off the mines or the mills will be.

Quite different is the situation with the queer and peculiar people—what we call the *paranoid* people. I wish the word paranoid could be generally used; it would fit so readily into headlines, and we could explain the Kaiser, or authorities nearer home, or anybody else by this term. These peculiar or paranoid people are ones that are neither inadequate nor in the usual sense subject to ups and downs of moodiness—they are on the contrary people with a slant or twist. You have probably all met them. Curiously enough, they are often very good workmen and among the 43 cases which were under review by us a great many were men who, so far as the details of their work went, were exceedingly good workmen. Some of them are lime-lighters, others contentious, suspicious, abusive, unappreciative of favors. The other workmen hate, despise, or avoid them. The manager looking at the detail of good work done wishes very much to keep control of so good a workman, or even to make him a model for the works, but the other workmen will have none of it.

We are inclined to feel that those who have to do with industry will recognize these three types of mentally inadequate, moody, and peculiar persons. But although it ought to be fairly easy to eliminate the inadequate by tests, it is less easy to fit the moody ones into their environment or to fit the industrial environment, particularly the fellow-workmen, to the peculiar or paranoid ones. Of course the inadequate or feeble-minded persons are of considerable use in the works and particularly in keeping straight and clean such devices as Dr. Darlington has just mentioned as necessary for the sanitation of the works. They ought to be utilized in the works as they ought to be utilized in the army for a variety of simple and useful processes.

As for the moody ones, I do not know enough about the industrial situation to know whether some vacation system, or system of special granting of favors could be devised to get the benefit of the excellent work done in the interval by these persons subject to nervous ups and downs; for it is a fact that between times, these persons are often superior in imaginative powers and in working power to their more normal fellows.

As for the peculiar persons, I have no idea what might be done with them. Such of them as are good workmen ought to be placed in single rooms for crosspatches and curmudgeons, who are, translated into scientific terms, often merely nothing but these so-called paranoids.

After all, this whole work as studied by Dr. Adler in his work "Unemployment and Personality" (*Mental Hygiene,* vol. I, January, 1917) and by Miss Jarrett in "The Psychopathic Employee" (*Medicine and Surgery,* September, 1917), is not much beyond an embryonic stage. I should want the big works, above ground or below ground, to employ somebody with some knowledge of human character, such as a physician who has been an alienist or has otherwise some sympathy with peculiar human nature, or else a psychologist, or professor of something or other, to look into these matters. You know how it is—these scientific physicians, psychologists, and professors are lying about everywhere, having to earn money in one way or other. They have nothing to do but write books; they can often be got—and this may remain so for another 50 years—for little or nothing, to deal freshly and eagerly with new theory. Of course some of these men are nothing but potential Bolsheviki, and I consider that it would be your duty as engineers to use these potential Bolsheviki in concrete work of this kind. If at any time you find a Bolshevik, it should be your policy to track him out and set him to finding out something. University men (some of whom, I may whisper, seem to have Bolshevist tendencies) ought to be utilized. A university man likes to be utilized I remember how I myself, as a university man, felt patted on the back when Mr. Read wanted me to speak before a meeting of practical men. I said to myself—now, There is recognition of philosophy, go to, son, proceed to New York and speak to these mining engineers! Even theorists of the paranoid trend can be made happy now and again by the gift of a little brief authority. You may be a perfectly happy teacher of economics in Switzerland, but go to Petrograd and there is the devil to pay. In short, utilization of the potential Bolsheviki is one of the big problems of the world at the present time. Of course some of these Bolsheviki are really running industrial plants, some even probably are presidents of the corporations; that is one way which the world has of utilizing men of the type. The psychopathic Rousseau overturns the education of the world; Mohammed, an epileptic with hallucinations, gets a backing of millions who believe in him.

Dr. Darlington insisted on a number of valuable things and, as he said, they ought to be obvious. The teeth and hands ought to be washed and all that. Somehow or other the control of these matters is not vested in the moderns. The control of many firms, from the efficiency standpoint, is, so far as I can see, often in the hands of persons who are too old and too experienced to understand physical hygiene, let alone mental hygiene.

Much has been said today concerning the liability of older men, the

more experienced men, to accidents. Experience really is a terrible thing. I should suppose that the experienced men would be likely to have more accidents. In the first place, the older you get the higher your blood pressure, as a rule, and then again, if you are confirmed in your success (whether as a miner or as a company president) your Bolshevist or paranoid tendency (if there was one) simply comes out more strongly. The obstinate, peculiar, old, paranoid miner of great experience simply will not believe in safety devices. Perhaps if Hindenburg and the others were not so old and we had an Alexander or a Napoleon with lower blood pressure, somebody might win the war earlier. There is perhaps no general on either side who has shown great originality. It has been known for many years that one of the great troubles in the world is old age, but it has not been so clearly understood that experience may often be one of the greatest disadvantages entailed by old age. The phenomena of the world are ever new and it is a question how much experience teaches the majority of men.

I should like to have the accidents studied from the standpoint of the age of the miners and other workers. Stanley Hall has written a book about adolescence, but I do not know that he tells exactly when adolescence ends. Of course it never ends with some people who are in some of our works. Stanley Hall's tables run to about the age of 25 or 26. Prof. James used to say that at about that age, one got a change of character—one wanted to make money or to marry or to do something else. One became a man of ambition with sundry designs on love or money or both.

I have not been able to stick very closely to Dr. Darlington's text. One disease, a leader on the physical side, namely, syphilis, touches my own work in mental diseases very closely. Take a case of syphilis that gets knocked on the head with a rivet. We have had such cases that then developed a syphilitic bone lesion, demonstrable by the X-ray, in the skull at exactly the point hit by the rivet. Should the company pay full indemnity to a man who had acquired syphilis which was responsible for the development of the bone lesion? Now with modern methods, it is easy enough to determine whether a workman has syphilis. It will not prove expensive, it is only a little bother to some fellow at the top of the machine to decide whether it ought to be done. From the army we are trying to eliminate such persons.

All victims of mental disease ought to be eliminated from the army and then not only will there be fewer problems of postbellum compensation for disease complications, but also the service will be better. I have been reading what German literature the censor would permit to come through. In some medical papers, the Germans themselves have noted some of their own atrocities which are plainly due to the alcoholism or mental disease of their soldiers.

Health, in short, as Dr. Darlington has said, is the very first thing.

In this relation, consider the Bolsheviki, how they grow! We in the field of mental diseases are very familiar with persons whose doctrines sound very near to Bolshevist doctrines. In some of the mental disease literature of the war, there are cases whose tirades run very close to the newspaper accounts of the Bolsheviki.

The very first question to arise in a situation of social difficulty or maladjustment is the question of disease, but this question must not be narrowly limited to physical disease, or the diseases which the public health departments have so finely dealt with during the last decades. We must include under the head of disease also mental diseases. And mental diseases must be held to include not merely the big insanities, but the little ones, the wee bits of mental disease that have no more to do with insanity than a cold in the head has to do with pneumonia. Yet these wee bits of mental disease of course count in the man's efficiency just as much as does a cold in the head. Probably many of you would rather have a pneumonia and get over with it in a few weeks than have a cold in the head for a period of years. These slight character defects that you may at first sight count among mental diseases are of the same distracting and efficiency destroying sort.

It may interest you to know that the next group of evils below the diseases that we deal with in social case analysis, are the evils of ignorance, of poor training, of poor education. Below the evils of disease and ignorance lie those that we may call vices or bad habits. Then again there are the criminals, and below all these, below the diseases, ignorance, vices, crimes, lies poverty or resourcelessness. The world facing a problem like that of the Bolsheviki ought to think of the evils to society in some such terms. Let us inquire whether the persons responsible for the social maladjustment are actually diseased in body or mind. Whether it is a matter of Mohammed, of Rousseau, of Bill Haywood, of Trotzky, or of anybody you like who is creating a new adjustment in society, whether a good adjustment or maladjustment—he should be analyzed from these standpoints. We should be able to give him a clean bill of physical and mental health before we evaluate what he is doing.

There was a report, I don't know how well founded, that Kerensky was a victim of a severe disease of the body; the medical man's immediate decision is that a man with tuberculosis of the kidneys could hardly last. If he lasted, it would be a nine-days' marvel. All of which has nothing to do with the fact that Kerensky was, according to all accounts, a great hero. What about such men as Trotzky, as Lenine? Is Trotzky subject to disease, particularly to some mental twist? Is he simply ignorant and poorly educated—is he vicious—is he reacting in the best way he can to a condition of poverty? I have my private opinion of Trotzky which I do not care to express here. As for Lenine, I should not think that he was a crook and, as to the analysis of his slant, that is not a matter for mining engineers today. These are questions that the world

must work with. In the Who's Who of the World, biographical studies are of the greatest importance. Medicine, education, ethics, law, economics, are of value in the analysis of the men we employ or permit to be our leaders. I plead here for an application of the medical point of view to this analysis, but by medical point of view I mean a point of view which takes into account the mental as well as the physical—a kind of mental medicine now in the making in which character defect, slight oddity, slants, and twists are subject to sound observation and skilful interpretation.

With all these sciences—medicine, pedagogy, ethics, jurisprudence, economics, hardly one takes proper account of the individual as such. Almost all are under the influence of the nineteenth century in dealing with men statistically. Please do not understand that I denounce statistics as such. My one point is that the one individual survives whatever happens to your statistics. Of all the sciences just enumerated as dealing with the great evils of the world, medicine comes nearest to dealing with the individual as such Education, to be sure, is beginning to consider the individual, as witness the excellent work of Prof. Whipple, who has shown how by intensive methods certain students could readily be made to do two years' work in one.

Ethics again might be thought to be a science that should deal with the individual and no doubt it has, but most of the books deal with group ethics and not with the ethics of the individual. As for the law, it seems entirely hopeless, dealing as it does with nothing but general principles and taking hardly any account of individuals at all. Still here we note with pleasure the appearance of judges who sympathize with the new work of Dr. William Healy on "The Individual Delinquent." As for economics, there still prevails the idea that there exists a so-called "economic man." I hope some day to be invited to some kind of organization of practical men to speak on the decline and fall of the economic man. It was I believe a banker, Ricardo, who got this idea over, and now social workers, Bolsheviki, and everybody else believe and talk as if there really were an economic man. The sooner we get out of the idea that there is a standard man, the better. And when we do so the works will get individualized, and the right people will be put to doing the right sort of work.

To be sure, I am not a psychologist, I am nothing but a psychiatrist. I am not even a technician in the sense of the man who understands personally how to do mental tests. I should not be able to make one skilfully, but I do say that the evidence is that these tests are winning their spurs. I believe the line officers of our Army themselves are reported to be more in favor of psychology than even the psychologists. I heard how the psychologists, in a brief interval, were able by their tests to strip a whole brigade of the good men they wanted for clerks. The line officers saw the point.

The Employment Manager and the Reduction of Labor Turnover

BY THOMAS T. READ,* E. M., PH. D., NEW YORK, N. Y.

(New York Meeting, February, 1918)

Summary

THE cost of labor turnover in industry is so large as to justify the adoption of almost any means to bring about its reduction. Intensive study has shown that faulty methods of hiring and discharging men is the most important factor in labor turnover. Complete control over hiring and discharging by the foreman is a relic of outgrown industrial conditions; centralized hiring permits this work to be put on a scientific basis and also does away with many serious evils that cannot otherwise be reached. Centralized hiring does not impair the authority of the foreman; he hires his men from the employment office and discharges them back to it, instead of from and to the street. The employment manager, being a direct representative of the employer, tends to restore the former relation of direct intercourse between employee and employer that was helpful in avoiding friction between them. Being a specialist, he is able to bring special knowledge and skill to bear upon the task of selling employment in his concern to desirable workmen; he is also able to give the foreign workman the special attention he requires. Employment managers have been used for the past few years by a number of large organizations, a few of which are engaged in the mining and metallurgical industries. They have invariably reduced labor turnover, in some cases to as little as one-tenth of what it had been. So great a reduction is due in part to other changes made in the light of the data made available by scientific study of the labor problem.

In my former paper on personnel work[1] I advocated the more general use of the employment manager in mining and metallurgical enterprises as a means of reducing labor turnover. The form of organization recommended seems not be to understood by all, and I have requested the privilege of explaining it at greater length, since it is perhaps the most important factor of all in personnel work, and has a vital influence on the cost sheet of every industrial enterprise.

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* Technical Dept., New Jersey Zinc Co.

[1] *Trans.* (1918), 58, 64.

What an Employment Manager Is

An employment manager is that member of a modern industrial organization who is charged with the specific duty of hiring men for the whole organization. The recent growth of corporate industry has led to the hiring of men in numbers that make it a task of first-class magnitude; in some cases twenty to fifty thousand men are hired in a year. No organization would think of buying supplies on such a scale without creating a special department to see that it was done in the most efficient and economical manner, and it is remarkable that industry has waited so long before putting the purchasing of so complex a thing as labor supply on a scientific basis. I have said the purchasing of labor; it would be more accurate to say the selling of employment, for the demands of industry at the present are such that the workman no longer has to go with his hat in his hand asking for a job; the representative of the employer has to go to the workman and endeavor to get him to accept employment. This is an additional and powerful reason why the employing of workmen for a given industrial organization should be put in the hands of a man who can bring special skill and knowledge to bear upon the work.

[Why an Employment Manager is Necessary

Labor represents more than half the cost of the finished product and it is more essential that labor shall be bought (or employment sold) by a man having special knowledge, skill, and aptitude than it is to have a purchasing department for raw materials. There are many other specific reasons why centralized hiring is desirable and profitable. In the first place, if hiring is done by foremen and the workmen are chiefly foreigners, it frequently transpires that the foreman is grafting on the men he employs, especially if labor is plentiful. It also builds up racial or religious cliques in a department that will make themselves felt in trouble later. This is inevitable, since the only source of supply a foreman has is through his friends and the friends of the men on his gang. The only basis of judgment the foreman has in interviewing an applicant for employment is the impression that the man makes on him, so he naturally builds up his gang with men who are all much alike. The methods used by foremen in hiring men are frequently such as to give applicants for work so bad an impression of the organization that they will go away and never come back again. There are too many foremen whose idea of discipline is essentially that of a slave-driver, and to allow such men to sell employment in their organization is little short of absurd. Discourtesy always comes home to roost, discourteous treatment of an applicant for work is a senseless waste of that precious asset, good will.

An equally vital group of reasons centers around the fact that the

foreman himself is frequently the cause of the necessity for hiring men. Men of initiative and energy may be fired simply because the foreman regards them as "too fresh." Individual mannerisms or peculiarities of the workman may prejudice the foreman against him, or the foreman may have mannerisms, a method of speech, or some other peculiarity that makes his men dislike him. Or the foreman may play favorites, sometimes quite unconsciously. Generally, however, there is nothing unconscious about it. Many, perhaps most, of us have carried a dinner bucket and a brass check and can testify from first-hand knowledge that the amount of intriguing for personal advantage that goes on in an industrial organization is of the same order of magnitude as that in politics or diplomacy. The foreman may even be incompetent, since the qualities of a good foreman are distinctly different from those of a good workman; many a good workman has been spoiled by promotion to foreman. An employment manager frequently discovers that the best way to better employment conditions is to get new foremen.

An equally vital reason is that few foremen make any systematic effort to fit a man to his job. Their education and experience seldom makes them sympathetic to the view that it is worth while to make much effort in this direction, although they would be the first to insist that a machine-shop job cannot be well done with the wrong kind of tool.

The foreman's chief duty is to keep up the output of his department and the hiring of men is merely an annoying necessity that he does not enjoy, so it is commonly performed in as summary a manner as possible. The only way the foreman has of judging the capabilities of a man is by looking at him and asking him questions. Many people think they are "good judges of character," whatever that may mean, but it has been scientifically demonstrated that the determined chin, thoughtful brow, sensitive mouth, and so on, of fiction writers has no basis whatever in fact, and in general that there is no connection between physical features and the characteristics and aptitudes of men. About the only thing that can be told about a man by looking at him is that if he weighs 110 lb. he would not be a good man to put at lifting heavy weights, or if he is 5 ft. 2 in. tall he would not be adept at a job where he had to reach high. If the man is a foreigner and does not speak English very well (which is all too frequently the case), asking him questions is productive of little more information about himself, for the chances are he only half understands what is said to him and replies "yes" to every question, in the hope of making a good impression. So the foreman puts him on and "tries him out," with a lamentably low measure of success in most instances. At a mine where I once worked the men walked in 25 miles from the railroad, were put on for a shift, and fired at the end of the day. The picture of those men walking down the trail with their blanket-rolls on their backs, while others hopefully struggled up, is indelibly en-

graved on my memory. The cost of such a method of securing workmen, to the mining company, as well as to the man himself, did not seem to impress itself on the management.

Even if the man is not summarily fired the foreman is seldom willing to devote much effort to teaching him. There was a time when it was possible to insist that a man should be thoroughly competent at starting in, but it is impossible to adhere to any such standard under present conditions. If the foreman was promoted because he was the best workman in his gang he is commonly irritable and impatient with the backward man. If he is the driver type of foreman (and the majority of them belong to the one type or the other) his main idea is to keep up production; acting as a teacher is a task he does not welcome and seldom performs well. When we couple with this the fact that the foreign workman is hard to teach, because he wants to make a good impression and so pretends to understand when he really does not, it is evident that "trying him out" is an expensive way of building up an organization. It should be mentioned here that many, perhaps most, cases in which a man is fired for disobedience to orders prove on careful investigation to be really a case of the man not understanding what he was told to do and taking a chance that he had guessed right rather than ask for more explicit directions.

The employment manager should have either at his own command, or among his assistants, all the languages spoken in the company working force, he should interview the applicants for work in circumstances and with surroundings that indicate to the man that he is going to get a "square deal," and by putting the man on at a simple job and transferring him he should be able to train the man up to higher grades of work. In short, hiring by the foreman is much like the old-fashioned method of making soap by boiling it at home in a kettle; the modern method performs the work more efficiently and gives a better product.

Methods Used by Employment Managers

Certain things are essential to success in centralized hiring of workmen. In the first place, the employment manager should be personally familiar with the work of the plant; if he has come up through the ranks so much the better. He should be provided with rough specifications as to the kind of men desired for a given kind of work, since the foreman must be suited, and the foreman's ideas may differ from those of the employment manager. He should have notice as far in advance as practicable of the number of men desired so he can provide them when needed. If he is not a linguist he should have assistants who are, and he should have the necessary clerical help to keep his records in order and relieve him of all work that an ordinary clerk can do, for the capable employment manager finds

it difficult to avoid being kept busy 16 hr. a day straightening out all sorts of difficulties that might be said to be no part of his duty, were it not that their inevitably coming to him indicates that they are.

The forms used in the conduct of an employment office are usually similar to those illustrated in the accompanying figures, are enumerated below (forms No. 4, 5, 6, and 10 of the list have not been reproduced for lack of space—Ed):

1. Requisition for help (sent in by foreman to employment office).
2. Application for position (made out by applicant if he can read and write English; this gives a record of his previous employment, and may be checked by inquiries from his previous employers).
3. Medical examination card. (This is retained by the physician for future reference and additions.)
4. Medical report. This is a slip taken by the applicant to the plant physician and brought back with the physician's report upon it

RC 1152 (10 C-4)

THE NEW JERSEY ZINC CO. (OF PA.)
PALMERTON, PA.

EMPLOYMENT REQUISITION

DATE.................................191

EMPLOYMENT DIVISION. EMPLOYEE FOR.................................DEPT. AS FOLLOWS

NUMBER OF MEN	KIND	TO REPORT FOR WORK ON	RATE

VACANCY CAUSED BY.................................

TEMPORARY / PERMANENT } INCREASE IN FORCE ON ACCOUNT OF.................................

SIGNED BY................................. | APPROVED BY.................................

Fig. 1.—Requisition for help.

This has noted upon it whether the man is first class, average, or defective in physique, and any special defects, such as color-blindness, poor vision, hernia, etc., are noted.

5. Hiring slip. Taken by the workman to the foreman who asked for him. This must be signed and returned to the employment office. In some of the most advanced organizations the foreman must fill in a complete statement as to the kind of work to which he assigned the man, what instructions he gave him, etc. The chief purpose of this is, of course, to impress on the foreman that he is expected to see that a green man is properly instructed in the work he is expected to perform.
6. Employee's record card. This is a complete record of all the information the company has about the man; this record is almost invaluable in case of wage or other disputes, and when any trouble arises over a man the explanation is often evident from a glance at his record card.
7. Employee's attendance card. This is self-explanatory.

THE NEW JERSEY ZINC CO. (OF PA.) PALMERTON, PA.

Application for Employment

Dated at ... . 191..

Name in full.......... ....Height ...Ft.....In Weight... Lb. Male or Female · .....

Address.......................... .... Religion . ...

Date of birth... .... .Nationality .... Married or Single Number of ... Children

(Month, day and year.)

What languages do you speak? . ... .Read? ....

What Public School did you attend?....... ....When Graduated? . . ..

What High School did you attend?......... ....When Graduated? . ...

What College did you attend?... ... .When Graduated?.... ... .

What Course did you take? ....Kind of Work Wanted..... ....

Have you any physical defects? .. . .Wages or salary expected?. . . ..

Have you ever been employed by the New Jersey Zinc Co. (of Pa.)?....... If so, when? .. ...

Have you any relatives in the employ of this Company? If so, give names . ...

Introduced to this Company by.... . ...

Name Address Business

Former Employers

Give the names of the firms you have worked for, beginning with the last	What Work did you do?	How long Employed?	Date of Leaving?	What Wages or Salary did you receive?
(Last Employer) Name.......... ... . Address...... .... Why did you leave?... .. .. Name................ .... Address. .... Why did you leave?......				

References

Name	Address	Business

Name of nearest Relative / Friend ... .

Address of same ....

Rules

Safety comes first; when in doubt take the safe course.

The making of any false statements in this application, as to name, date of birth, previous employment or other points will be considered cause for discharge

The loaning of employee's entrance checks, or registering on time clocks for another will incur immediate discharge.

Employees shall register the time on the time clocks whenever entering or leaving the plant.

Employees neglecting to register their time when the clocks are in service, will lose one-half hour's pay from the time that they commence work, and if this is persisted in the offenders will be discharged

Any employee registering in late will forfeit the time he loses, the time being figured from the next even quarter hour.

When an employee registers out early the time will be figured to the last even quarter hour.

The taking into the plant, or the use of any alcoholic drink within the plant, is absolutely forbidden.

Any employee wishing to be absent from duty must, before going, apply to and receive permission from his immediate superior.

All employees are expected to exercise care and economy in the use of materials and supplies, and any employee who, through carelessness, or malice, wastes materials or destroys the property of the Company, or is found stealing or carrying away the property of this Company will be discharged.

Any workman offering money, liquor or valuables of any kind to a foreman, boss or clerk will be subject to discharge, and any foreman, boss or clerk accepting money, liquor or valuables of any kind, from workmen, will be summarily dismissed.

Chiefs must pay strict attention to the rights and privileges of all employees, hear and give prompt attention to any reasonable complaint or claim for redress made by any employee, and not to allow any discrimination on account of nationality or creed.

Every salaried employee of this Company is expected to devote his entire service to the work and interests of his employer, and he is forbidden to take an active part in the management of any other business, or to carry on any of its work.

If I lose my employee's entrance check I hereby authorize the New Jersey Zinc Co. (of Pa.) to deduct from the wages due me, the sum of fifty cents ($.50).

Remember that while every man is hired to do some particular work, the safety of himself and his fellowmen is more important than that work.

Employees shall report immediately to the foreman, or man in charge, all accidents and attacks of sickness occurring on the plant, however slight, so that they may receive proper attention.

I, the undersigned, agree to abide by the above rules.

Signature....................................

FIG. 2.—APPLICATION FOR POSITION.

8. Transfer card. This is the journal record of the transfer of a man from one job to another. The initiative in this may come from the man, who wants to get into new work, from a foreman who wants him, from his own foreman who wants to get rid of him, or from the employment department.

BC 1288 (15-7-[illegible]

THE NEW JERSEY ZINC CO. (OF PA.)

EXAMINATION CARD

NAME NO DEPARTMENT DATE
OCCUPATION PRE EMP DATE OF EMP
CHILDREN OTHER DEPENDENTS
AGE SEX S M W NATIONALITY RESIDENCE
HEIGHT WEIGHT CHEST-INSP EXP UMBILICAL
GENERAL APPEARANCE COMPLEXION HAIR
EYES EARS NOSE
THROAT GUMS TONGUE
NECK CHEST CONTOUR
HEART
LUNGS
ABDOMEN
INGUINAL REGION G U
EXTREMITIES BOWELS
SPINE SKIN
PULSE B P
URINE
SMALL POX VACCINATED
FIRST CLASS
AVERAGE } SUBJECT FOR POSITION
DEFECTIVE
REMARKS

MONTHLY INSPECTION

DATE	GENERAL CONDITION	WEIGHT	DAYS LOST OCCUPATIONAL DISEASE	DAYS LOST SICKNESS	DAYS LOST ACCIDENT	DAYS LOST OTHER CAUSES	TOTAL	REMARKS

SEMI-ANNUAL EXAMINATION

DATE	PULSE	HEART	LUNGS	URINE	REMARKS

FIG. 3.—MEDICAL EXAMINATION CARD.

9. Leaving slip. This must be taken to the employment office and slip No. 10 issued by the employment manager before the man who is leaving or has been discharged can get his pay. In a modern organization no man is allowed to leave without a searching inquiry into his reasons for doing so. His explanation should be carefully recorded and checked by inquiry from other sources. The following form of chart used by the Montgomery, Ward & Co. employment department is a good form of analysis:

Classification of Causes for Removal from Payroll

Other Positions
1. Better salary.
2. Former position.
3. Going into business.
4. More promising position.
5. Position nearer home.
6. To learn trade.
7. To return to trade.

Leaving city.

To marry.

Health

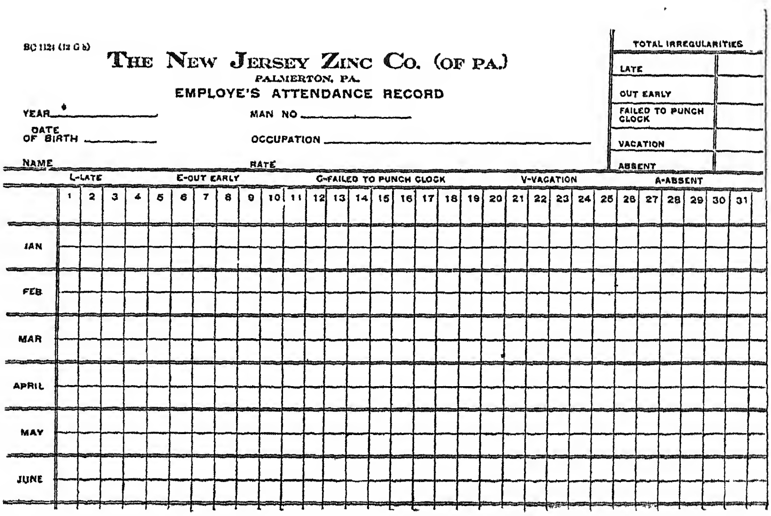
On account of health.
1. Own accord.
2. Division Supt.'s a/c, Dr.'s orders.

Dissatisfied
1. Did not like supervision.
2. Distance too great.
3. Refused temporary work.
4. Refused to be transferred
5. Resented criticism.
6. With salary.
7. Did not like working conditions.
8. Work too hard.

Unsatisfactory
1. Agitator.
2. Carelessness.
3. Dishonesty.
4. Drinking.
5. Fighting.
6. Financial difficulties.
7. Indifference.
8. Insubordination.
9. Irregular attendance.
10. References.
11. Supt.'s private file.
12. Suspected of pilfering.
13. Too slow.

Reduction of force.

No Reason
1. To go to school.
2. To stay at home.
3. Worked less than two weeks—failed to report.
4. Worked more than two weeks—failed to report.


BC 1121 (12 G b)

THE NEW JERSEY ZINC CO. (OF PA.)

PALMERTON, PA.

EMPLOYE'S ATTENDANCE RECORD

YEAR ____ MAN NO ____

DATE OF BIRTH ____ OCCUPATION ____

NAME ____ RATE ____

TOTAL IRREGULARITIES	
LATE	
OUT EARLY	
FAILED TO PUNCH CLOCK	
VACATION	
ABSENT	

L-LATE E-OUT EARLY C-FAILED TO PUNCH CLOCK V-VACATION A-ABSENT

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
JAN																															
FEB																															
MAR																															
APRIL																															
MAY																															
JUNE																															

FIG. 7.—ATTENDANCE CARD.

BC 1151 [10-C-4]

THE NEW JERSEY ZINC CO. (OF PA.)
PALMERTON, PA.

EMPLOYE'S TRANSFER CARD

NAME				TRANSFERRED TEMPORARILY TRANSFERRED PERMANENTLY
FROM DEPT.	OLD NUMBER	TO DEPT.	NEW NUMBER	TO TAKE EFFECT
OLD POSITION		OLD RATE	ENTERED PAYROLL DIV. RECORDS BY	
NEW POSITION		NEW RATE	APP'D EMPLOYMENT DIV. ENT'D REC'DS	
FOREMAN TRANSFERRING	CHIEF'S APPROVAL	FOREMAN RECEIVING	CHIEF'S APPROVAL	

THIS FORM IS TO BE MADE OUT BY THE DEPARTMENT LAST EMPLOYING AND FORWARDED WITH THE EMPLOYEE WHEN GOING TO DEPARTMENT DESIGNATED TO RECEIVE HIM. THE RECEIVING DEPARTMENT WILL COMPLETE THE FORM AND FORWARD SAME TO THE EMPLOYMENT DIVISION WHICH DIVISION WILL PASS UPON IT AND FORWARD TO THE TIME DIVISION. A RECORD OF THIS TRANSFER WILL BE MADE BY THE EMPLOYMENT OFFICE AND TIME DIVISION, AND THIS CARD SHALL BE FILED WITH THE EMPLOYMENT RECORDS.

REMARKS

FIG. 8.—TRANSFER CARD.

BC 1578 (10 C-4)

A.

THE NEW JERSEY ZINC CO. (OF PA.)
PALMERTON, PA

TIME SLIP

PAY ROLL DIVISION: DATE ....

PLEASE PAY THE

AMOUNT DUE HIM .... CHECK NO. ....

WORKED TO-DAY .... HOURS	FOREMAN'S SIGNATURE ....
PERSONAL BELONGINGS COLLECTED AND OUT OF PLANT .... FOR DEPARTMENT	BRASS CHECK COLLECTED BY .... FOR DEPARTMENT

LAID OFF WORKED NOTICE QUIT DISCHARGED

THE PAY OFFICE WILL BE OPENED AS FOLLOWS { 9-10 A M / 2-3 P M } EXCEPTING SATURDAY AFTERNOONS, SUNDAYS AND HOLIDAYS

B.

THE NEW JERSEY ZINC CO. (OF PA.)
PALMERTON, PA

TIME SLIP

NAME	CHECK NO.	DATE

LAID OFF WORKED NOTICE QUIT DISCHARGED

FOR ....

CHARACTER AS A MAN AND AS A WORKMAN: ....

DO YOU ADVISE HIS RE-EMPLOYMENT?	IF SO, AFTER WHAT PERIOD?	FOREMAN'S SIGNATURE

THIS SLIP MUST BE COMPLETELY FILLED OUT

FIG. 9.—LEAVING SLIP.

The committee on labor turnover of the Boston Employment Manager's Association has developed a standard form for analyzing and recording labor turnover. These forms are kept in stock by the Library Bureau.

These interviews with men who are leaving are productive of most valuable information since they reveal objectionable conditions that in many cases can easily be remedied and that are actually a disadvantage to the company as well as to the workman. What I wish to emphasize here is that the workman is the only one who is in position to press for the amelioration of such conditions. The foreman is trying to get the superintendent to allow him to have some new machines or something that he regards as better than what he is using, the superintendent is trying to secure authorization for a lot of new equipment or possibly the adoption of a whole new process and both of them are so absorbed in what they regard as being of prime importance that a better lighting or ventilation system, a change of layout so as to make things more convenient and comfortable for the men, an adequate change-house, or a clean place to eat their lunch is deferred because it is not easy to prove conclusively that it is profitable. If the general manager is interested in these things and they come to his attention he is likely to put them through, but it is seldom indeed that circumstances under which the average foreman works conduce toward his making much effort to improve working conditions for his men.

Under this system no man is permitted to leave the organization unless it has been clearly proved that this is advisable. Sometimes several transfers will be necessary before the man gets into his right place and it must be remembered that trying the same man in a number of different places costs less than trying an equal number of different men, which would otherwise be necessary. It would be easy to cite numberless instances of men who were failures at one or several jobs, only to make a success when they were rightly placed, but every operating man can supply these from his own memory. The centralized employment bureau is the only agency that is equipped to handle the problem of distinguishing between the man who is no good and the man who is wrongly placed.

What Employment Management has Done to Reduce Labor Turnover

In most instances where centralized hiring has been introduced other changes have been made at the same time, frequently amounting to a complete change in the attitude of the management toward labor problems. Under such conditions it is impossible to determine with accuracy how much of the improvement has been the direct result of using an employment manager. I will recite some of the published figures without vouching for their accuracy.

The employment department of the Saxon Motor Car Co. is credited with reducing the labor turnover of that organization to 40 per cent. of what it had been in the first year of its operation. The Hayes Manufacturing Co., of Detroit, diminished its labor turnover one-half the first year, and another one-half the second year, while the output per man increased 30 per cent. The Solvay Companies, of Detroit, reduced their labor turnover rate from 10 per cent. per month in May, 1916, to 2.4 per cent. per month in December. Fayette R. Plumb, Inc. of Philadelphia, reports that employment management reduced its labor turnover 48 per cent., enabled them to decrease their working force 10 per cent., to reduce the working time 9 per cent. and at the same time increase their total shop production 10 per cent. I cannot give figures for the few companies connected with the mining industry that have adopted centralized hiring, for none of them seems to have records that would show what their labor turnover really was before adopting it. It may be said, on the other hand, that the chief reasons why companies are slow to adopt such a system is that they do not have the records to show what their labor turnover is and so do not know what it is costing them. The figures are truly amazing; for example, in such an organization as the Bethlehem Steel Co., labor turnover probably costs at least $3,000,000 per year.

Some Limiting Conditions

Some governing conditions must be observed if a trial of employment management is to be a success. The whole thread of the argument up to this point has demonstrated that the employment manager must be of distinctly a higher type than the average foreman. A college-bred man who has had experience as a foreman will do, when he has developed beyond the foreman stage. It is difficult to draw up specifications for an employment manager, but it may be said that he should have worked as a day-laborer himself, have been a foreman or superintendent of labor, but should not have had too much experience in any one department of the organization, lest he overemphasize that and slight the others. He should be familiar with working conditions in every part of the plant. He should be married, have children, and be over 30 years of age, otherwise he will not have had sufficient experience of the problems of human existence and will be too cocksure of his own judgment. On such matters as labor unions, the open shop, capitalism and labor, and so on, his attitude should be one of broad-mindedness, which means that the Board of Directors will suspect him of being a Socialist and the workmen will tend to regard him as the hired apologist for what Hearst calls "the plunderbund." To survive this state of affairs he will need to be something of a philosopher, and if he has infinite tact, patience, diplomacy, and wisdom, it will be none too much for his needs. He should have a gift for acquiring and retaining the friendship of the men with whom he comes into contact,

the power of compelling people to do what he wishes them to do without seeming to exert pressure upon them, good executive ability, enormous capacity for detail, ability to keep his temper under the most trying conditions, and be willing to work almost day and night. In short, the ideal employment manager should be of the type that big organizations are willing to pay large salaries to secure, but whom they have never been intelligent enough to devise any systematic method of developing. It is, of course, impossible to secure such a man for a salary only a little above that of the ordinary foreman.

Another aspect of this feature is that a man's rank in the organization inevitably depends largely on his salary. No one who ranks low in the

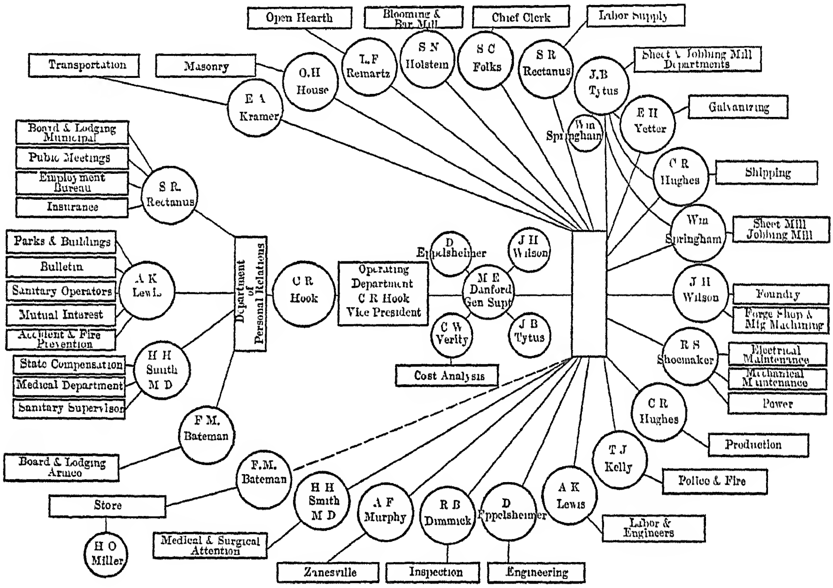


FIG 11.

organization can do effective work of this kind, because he is not in a position to make his views prevail. A good case in point is the failure of the first British campaign in Mesopotamia, which was proved to be due, not to the inadequacy of the medical department, but because the medical officers did not rank high enough to be able to insist that the necessary preparations be made and precautions taken. In the same way, the horrible sanitary conditions that prevailed in the training camps in the Spanish-American war were due not to the ignorance and inefficiency of the medical officers but simply to the fact that they did not rank high enough to get their recommendations carried out. Unless the employment manager ranks high enough to influence the general policy of his work it will be ineffective. Many companies recognize this; the best example at hand of a well-organized company is the American Rolling Mill Co.

As will be seen from the accompanying diagram the employment manager reports directly to the vice-president in charge of operations. In the Jeffrey Manufacturing Co., the employment manager is assistant secretary of the company, and with Fayette R. Plumb, Inc., he is assistant superintendent of the plant. Men of less rank have done good work in other organizations, but they have been handicapped in doing it.

Recapitulation

1. The cost of labor turnover in industry is large enough to justify extensive measures to reduce it.

2. Centralized hiring is the most effective means to reduce labor turnover.

3. Hiring by the foreman is a relic of outgrown industrial conditions.

4. Centralized hiring does not impair the authority of the foreman; he hires his men from the employment office and discharges them back to it instead of to the street.

5. Relieving the foreman of the labor of looking for men gives him more time for the performance of his proper duties and improves his efficiency.

6. The employment manager, being a specialist, is able to devote special skill and knowledge to the art of selling employment in his organization to the workman.

7. The employment manager is able to give the foreign workman the special attention he requires.

8. The employment manager also tends to restore the former conditions of direct relations between employer and employee and hence brings about a better esprit de corps in the organization.

9. The methods used by employment managers are much along the same lines in every industry, as human nature is much the same everywhere.

10. The results that have been attained through centralized employment speak for themselves.

11. The employment manager must be given sufficient rank, otherwise he cannot work effectively. A high type of man is required and the saving he is able to make justifies the cost of securing such a man.

DISCUSSION

E. E. Bach, Ellsworth, Pa.—A personal interview with a man is one factor in reducing labor turnover; his working conditions is another, while the conditions under which he brings up his family is still another; all have much to do with the reduction of labor turnover. A man well placed, happy in his work and happy in his home, will stay put and incidentally decrease the labor turnover in any industry.

C. R. Hook, Middletown, Ohio.—I am so deeply and sincerely interested in the employment problem, that it is very difficult for me, once I

get started, to know when to stop. In the first place, I want you to understand that I realize that what may be a possible accomplishment in the plant with which I happen to be connected, may not be possible of accomplishment in the same way in your plant. Our problems might be quite different; our location might be quite different, and therefore our employment problem would be very much affected by the community conditions. Two of our plants happen to be located in a town of about 25,000 people, Middletown, Ohio, and the employees of our plant represent about 55 per cent. of all the industrial employees in that town. Therefore, we have an opportunity, a very great opportunity, of affecting the general civic conditions of our community, and it is reflected back in the kind of men who come to our gate for employment. Now it is essential, in my opinion, to have a well-organized, a well-coördinated employment bureau. First, when a man comes to take employment in your plant, his spirit and his loyalty and the efficiency that he is going to give you are going to be largely affected by the opinion that he gets of your company through the way he is treated when he is first met. If he walks up to the gate and some fellow says to him, "Well, what do you want?" "I'm looking for a job; I'm a machinist." "What's your name? Where have you been working?" "All right, here's a pass, go on in and see Jim Johnson; he'll take care of you." The man feels a kind of rankling; that was not the way he expected to be greeted; he is not extending any very great service to this company that he is going to be employed in; they have not extended any great service to him, as yet. But if he goes to any employment bureau and somebody meets him and says, "Good morning, John; how are you this morning? What can I do for you?" "I am a machinist; I'm looking for a job." "I am not sure whether we have a job for a machinist right now, but we will see. Step over to this window and this young man will take care of you." John is interviewed, and if they need a machinist over in the forge machine shop, John is escorted over to the forge machine shop after he has been interviewed by the employment department. If they have made up their mind that he is an available candidate, he is escorted to the foreman of the forge machine shop, who gets a chance to talk to him. If the forge machine shop foreman is satisfied with John, and he generally is after the employment department gets through with him, he says, "I would like very much to have you take a job here; suppose you go back and get your blue card and tell the employment department that I will use you tomorrow morning, starting with the 8 o'clock shift; and John goes back with the escort to the employment department and feels pretty good over his interview and he gets a blue card and a check and the next morning when he comes in he goes to the time-keeping department and gets his clock card and goes through the usual operations of getting into the plant; and he goes over to the forge machine shop—he now knows the way, if he does not he will be told courteously how to get there, and meets the foreman again and the

foreman tells him something of company policy. We insist on that. The foreman tells him the particular things that are going to help him get along in our company. He lets him know first, and don't forget this, that the boozer has no great future ahead of him in our works; and we bring that out first, for it is of primary importance. And he is talked to on the subject of safety; and after the foreman gets through with him, he is turned over to the chairman of the shop safety committee who takes him over the shop and tells him about the safety devices and how to use them and about being cautious on the particular job he is going to perform. I think that he will pay more attention to the question of safety than if the foreman alone had told him.

You cannot separate the medical department, the safety department, and the educational department from the employment bureau. They are all dovetailed one into the other, and if you are going to get real results from any one of these four departments, it is absolutely necessary that you coördinate their efforts so that they will function together. In our plant I happen to be the vice-president in charge of operations, and the chief surgeon, the director of safety, the director of employment, and the director of education form my little cabinet of personal relations, and we work out our problems together. It would take me several hours to explain our system in detail to you, so I will not attempt that but will simply say that we have it so arranged that the man is served by all of these departments at one time or the other. We never use the word "welfare" in our plant; we always use the words "mutual interest;" because we do not believe in welfare work as ordinarily understood. We try not to do anything until the organization is ready for it and they themselves want it; then you get real results from what you put into it. You have got to go around the back way at times and help them get ready to want it, of course, through different methods of education, explanation, and instruction, so that they will see the value of the thing that you are going to do. I tell Mr. Morris, our safety engineer, "Frank, your job is not having your inspectors discover gears that are unguarded, holes that have no rails around them and things of that kind; your big job is to sell safety to the men of this plant and sell it to me too and keep everlastingly at it." As Mr. Read has well said, you have got to sell the job to the man and when you really sell him a job in your company he says "By gum, that's the best company I ever worked for" and he is going to give you more efficiency than he ever gave anybody else.

The questions of gardens is an illustration. Last year we set aside some 200 acres. You cannot all do that, because you haven't the ground, but we happened to have it in connection with our plant. We divided it off into lots 50 by 150, making 640 of them altogether. They varied in size, but that is approximately the size, and out of the 640 that were allotted, only seven of those who started failed to finish. That is a pretty fair record, for although seven stopped, we re-allotted the plots

and all 640 of those gardens were actually cultivated. Prof. Cruikshank, of the Ohio State University, Department of Agriculture, came down and looked over them while they were growing. I wanted him to do that so that he could come down later in the fall and judge the exhibits which we had. He said that he never saw a set of gardens more diligently cultivated than those gardens were, and he estimated that, by the end of the season, $30,000 worth of produce had been taken off of them. A great many things were accomplished through the means of those gardens. The man's mind was kept active on things worth while instead of having time to run down to the corner saloon and hear some radical tell about the capitalists making a slave of him, thus inducing him to become active in some socialistic society. We had a capable man go around and watch those gardens, one who had been a student of agriculture and had actually practised 4 years in Michigan; when he found bugs on the tomatoes he told the man what to do and helped him get the bugs off of them, took a personal interest in it, and that is why the gardens produced well.

As an illustration of what social disease is probably doing in your plant and many other plants, we took the other day 100 colored men, just offhand, as they came wanting to be hired, and we examined them; 27 of them had active cases of syphilis and gonorrhea; 34 admitted they had had it and of the other 39, who said they had not been infected, the doctor said most of them showed the marks. Now you can imagine the inefficiency that there is in industry when you have such a large percentage of men contaminated with disease. You know how a man is going to do his work at a lathe or a mill or anything else when he is worrying, not about his job, not about doing the work particularly well, but when he is feeling rotten and scared to death about what is going to happen to him. You know what kind of work you are going to get out of him. That subject, too, needs a great deal of attention.

There is nobody that gets as close to the individual as the doctor. He has a wonderful opportunity, and through the coöperation of the doctor and the Director of Employment, many problems can be solved. Only last week I had occasion to have a little conference with one of the doctors. We have a chief surgeon and two assistants who are giving all their time to the work. A man from the forge shop went over to the hospital to have a wound dressed and he was permitted to sit there on the bench longer than he should have been. The doctor admitted that he was reading an article, was just about to the end of it and he thought he would just finish a couple of paragraphs before attending to the man. The man saw it and I heard about it and talked to him about it and the doctor went and saw the man afterward. This is the point I want to bring out, the doctor went to him afterward and said "Old man, I am awfully sorry I neglected you the other day, I had no business doing that, it was just thoughtlessness on my part," and he removed the offense, but if that man

had gone away feeling he had been neglected and that because he was simply a laborer in the forge shop, they did not care about him, he would have gotten an entirely wrong impression of the company he was working for and would have taken it out on the company by inefficient work. As it was, the occurrence was forgiven and we will get an entirely different class of work from that man than we would have gotten otherwise.

The superintendent of the Mutual Interest Department has under him the visiting nurses. He has had charge of instruction in English and Citizenship. Recently we arranged with Dr. A. J. Beatty to come to Middletown on June 1, to take charge of all of our educational work. The Mutual Interest Department travels about the town and ascertains the home needs of the individual We are trying to find out where we can be helpful, where the individual wants us to be helpful, not where we think we can be helpful. We do not try to cram it down his throat and say "Here is something you ought to have, and we are going to provide it for you and you take it." We do not believe we will ever get anywhere that way. We believe that very careful study must be made to find out where you can really be helpful and to be sure your men want you to do a thing before you do it. To illustrate that one point, let me cite our food supply store, which has been tremendously helpful this winter. For a year the superintendents, various ones, had tried to impress me with the fact that we ought to have a store. They said "Our men are being charged outrageous prices out in the town, and as soon as they know that a man comes from the rolling mill—and they know they make big wages out here—they charge him about 25 per cent. more." I replied "Well, we cannot consider a thing of that kind unless the men want us to do it." A little more pressure was brought to bear and finally a committee waited on me and said "Mr. Hook, we ought to do this thing; you don't know what a help it will be to the men of this plant if we can put a thing of that kind across." I told them to go back and have the men of the various departments say what they thought about it. In a little while I got a whole bunch of petitions signed by several thousand men, urging me to put it up to our Board of Directors. I discussed with our President, who is a human man and is in constant touch with the plant and knows as much about it as any of us; I explained the proposition and he said "There is nothing left for us to do, of course we will do it."

So we started that store a year ago last January, and any number of the men have sent me letters, saying that it has meant far more than an advance in wages to them. Some of the poor fellows know that when they get their pay envelopes, they will stop, maybe on the way home, and spend some of it for booze, and they want some opportunity to put part of that money into food, if they can, before they get led away. They buy coupon books, or give an order at the time-keeping department on their money, and it is deducted on pay-day, so they can buy a

$5 or $10 book and take it home and their wife gets it and then she can go and get the groceries at a price ranging from 15 to 40 per cent. under what is generally charged.

There is no use in my trying to tell you in a few minutes all the things we try to do. It is not any one thing alone that counts, it is doing all the things that you can do to be of real service, and the moment anything is done in a paternalistic manner, it is worse than lost money; you not only do not get any results, but it reacts against you. The men get suspicious; they say "Here, if this fellow can afford to spend $5000 a month for a proposition of this kind, my God, he must be making an awful lot of money off of us; why don't he give it to us in the pay envelope?" That is particularly true with insurance schemes. One thing I would especially urge you to do, and that is to get the men themselves to take an interest in all these activities. Some 14 years ago, when I was night superintendent, I discussed with a number of the men the proposition of organizing a mutual benefit association. They all know me around the plant as Charlie, and they said "Charlie, you call the meeting;" so they decided where we would have the meeting, and we had 80 there on a hot summer afternoon, July 11, 1903, and organized the Armco Mutual Benefit Association, the object being to provide a means whereby the men could contribute to a fund, and if they were ill, they would get a weekly benefit, and also to provide a means of getting together and forming an association where they could get together for their mutual enjoyment. That organization has grown until now it has 4875 members. All the men now become members of the Association when they are employed by the payment of a dollar fee in cash and 50 c. a month. The men run the Mutual Benefit Association themselves; the company has nothing to do with it, but if any serious problem comes up in their organization, they always come to me and ask me if I won't come to the meeting and help them. The question of deciding how many Liberty Bonds they would take came up, they sent for me and I told them I thought if they subscribed for $3000 of the bonds that would be fine. Immediately one of the men jumped to his feet and said "We will subscribe for $5000;" and so they did. We contribute about $200 a month to the Association by paying the secretary's salary and a few other things, but they are running it. They have checker parties, card parties and everything under the sun; they have a baseball league of five good teams and if you come to our town on Saturday afternoons you will see a couple of games as good as you ever saw anywhere, for they are good players. It has been very helpful and a valuable adjunct to the employment bureau, an adjunct upon which you cannot fix the value.

The question of housing is important; I do not think there is anything more important. A company must take an interest, as I have said, in all those things in the community which react to the benefit of the man's

home and family. Nine years ago, before we started the construction of our new plant which was to cost five or six million dollars (it has now run to probably ten) we had a meeting of the Board of Directors, the President invited me in to discuss this matter, and we decided that some provision must be made for proper housing of the men who were coming to us. We wanted men who were home-owners, if we could get them; or men who wanted to be home-owners. The essential thing is to give them the opportunity to become home-owners. I said "Let's organize a company in the town and get the people in the town to pledge their support to this program. We will put our money into it as individuals." I put in all I could personally, and our President did the same and others of our Board of Directors; but the company is managed by the men of the town. The Board of Directors of the housing company consists of seven men, and there are only two of our company on that board; members of our organization control possibly 75 per cent. of the stock, but the manager is not in anyway connected with our plant. The Executive Committee, outside of myself, are not members of our organization, but we went out and got options on the ground and land, and the first thing we did was to pass a resolution that we would place in the deed for every piece of ground a provision so that at no time in the future (we had attorneys go into this carefully) could there ever be a saloon of any kind whatever upon it, and there never has been on any of the property that has been sold. Since 1909 I have been acting as president of the company without compensation, as I think it is part of my job at the plant.

Last year our total expense for house building was some $325,000. Among others, we built 43 houses, each one separate on a lot 40 ft. wide by 200 ft. deep, for colored men, and everyone of those houses is sold and every man who has bought one of those houses has kept his payments up. We let them make payments as low as $25 down and $20 per month, but they are all keeping their end up and they are happy, contented colored men. The colored man is naturally a home-lover, I don't care if it is only a little shanty, he is naturally a home-lover, a home man, and if you want to get efficiency out of him, I think the thing to do is to give him an opportunity to get a home of his own. A very large number of our foreign-born workmen now own their own homes in Middletown and everyone has an excellent garden. We have tried in every way possible to make it easy and convenient for them to purchase their own homes, and have tried in every way possible to keep down the number of homes that the company itself owns. A certain number of houses which must be rented are available to take care of those who want to keep boarders, etc. The housing problem is very important and it should be given a great deal of attention, for it is directly and intimately connected with your employment problem in all its phases.

Principles and Problems of Oil Prospecting in the Gulf Coast Country

Closing discussion of the paper of W. G. MATTESON, continued from page 491.

G. SHERBURNE ROGERS (written discussion*).—Mr. Kennedy's discussion[1] of Mr. Matteson's paper takes the form of a criticism of my own comments[2] on this paper. Mr. Kennedy is a respected authority on matters pertaining to the salt-dome oil fields, and his characterization of my "elaborate figures" as "worthless" is sufficiently candid and comprehensive to warrant a brief reply.

My "voluminous figures" consisted simply of a rough estimate of the minimum quantity of salt in the Humble dome, and a calculation of the volume of sea water and of the volume of saturated brine which this salt would represent. Mr. Kennedy apparently interprets my remarks as opposing the idea that so large a volume of salt could have been deposited from sea water, for he cites the area and thickness of European salt beds; but nothing was further from my intention. Given an arm of the sea, an arid climate, and evaporation under a hot sun, it is easy to conceive the formation of almost any thickness of bedded salt. I cited the figures in connection with Harris' theory of the origin of salt domes, according to which the plugs were formed by the deposition of salt from ascending brine solutions, owing to the drop in temperature as they neared the surface. I pointed out the well known fact that the solubility of salt is only slightly affected by temperature, and that a drop of 80° C. would cause the deposition of less than one-tenth of the salt in solution; hence that more than ten times the volume of salt actually forming the plug must have been involved. If ten times the salt actually in sight be computed in terms of brine and multiplied by 50 or 60 to take into account all of the known salt domes, the resulting figure is so enormous that I am not at all so sure as Mr. Kennedy seems to be that the porous stratified rocks of eastern Texas and western Louisiana could contain or furnish so great a volume of migratory brine.

Mr. Kennedy, however, does not dwell on drop in temperature as the cause of the precipitation, but contents himself with ascribing the whole process to lateral secretion. As I understand it, this implies that the connate waters and brines contained in the rocks migrated to the Gulf Coast region, and there deposited their salt at various *loci* of crystallization. Just what started the crystallization or what force caused the

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* Received July 18, 1918.

[1] P. 490.

[2] P. 476.

waters to migrate to these points, and there give up all their salt, is not clear; nor is it stated whether the water itself, thus suddenly deprived of its salt and made fresh, remained in the rocks or flowed out on the surface as a huge spring. Harris' idea of precipitation through loss of temperature can at least be measured in the laboratory, but the mysterious force advocated by Mr. Kennedy baffles investigation. Years of discussion by students of ore deposits failed to elucidate the mechanics of lateral secretion, or to establish its importance as a geologic process. Further argument appears fruitless, for lateral secretion would seem to be a matter of faith and, therefore, outside the realm of debate.

Mr. Kennedy also takes exception to my reference to paraffin earth as an indication of oil, and states that many "worthless wells have been drilled" because of it. Opinion as to its reliability seems to be divided[3] and I did not venture my own estimate of its value; I simply stated that it should be included in any list of indications of oil. I know that it is by no means infallible; neither are salt or sulphur springs, gas seeps, or asphalt deposits, or even salt domes themselves.

[3] W. E. Wrather, for example, states that paraffin earth "may be classed as one of the most important indications of oil along the Gulf Coastal Plain." *Bulletin* 139 (July, 1918), p. 1152. See, also, Lee Hager's discussion of paper by A. D. Brokaw, "An Interpretation of the So-called Paraffin Dirt of the Gulf Coast Oil Field," *Bulletin* No. 140 (Aug., 1918).

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[NOTE.—In this Index the names of authors of papers are printed in small capitals, and the titles of papers in italics. Casual notices, giving but little information, are usually indicated by bracketed page numbers. The titles of papers presented, but not printed in this volume, are followed by bracketed page numbers only.]

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